CARL J. FRIMANN CLAUSEN
CONSULTING CIVIL ENGINEER

BEAST

A Computer Program for Limit Equilibrium Analysis by the Method of Slices

Report 8302 - 2

Revision 0, 5 October 1988
Revision 1, 24 April 1990
Revision 2, 15 October 1993
Revision 3, 10 August 2000
Revision 4, 24 April 2003

Cidex 424 bis
F-06330 Roquefort les Pins
France

Telephone (+33) 493 775 275
Telefax (+33) 493 771 979
e-mail cjfc@gf-net.com

CONTENTS

1.0 SUMMARY

The report presents the documentation of computer program BEAST. This program may be used for limit equilibrium analysis of cases involving slope stability, bearing capacity or earth pressure calculations.

BEAST is an interactive menu driven program that allows the user to try different shear surfaces, to modify control parameters, etc. during the program operations.

This documentation report covers the following main topics :

General Description

Gives a summary of required input values and procedures used by BEAST to solve a given problem. Size limitations and computer requirements are presented.

Engineering Documentation

Gives a detailed description of geometry modelling, soil parameters and load calculation. The governing equations are formed and the different solution procedures that may be used by BEAST are briefly explained. More detailed descriptions are included in Appendix E.

User's Guide

Gives a detailed description of the input data file to be prepared before a case is analysed. The interactive communication between user and program is explained. The section also contains a description of output generated by BEAST, including warnings and error messages.

Program Maintenance

Gives a description of subroutines, input/output files and the common area. Procedures for program modification are explained.

Examples

Appendix C to this report contains 13 examples with descriptions, input files and computed results. These examples are intended both for self studies and for program checking purposes.

Acknowledgements

During the work with BEAST a number of colleagues have contributed with material and points of view. This includes K.H. Andersen, R.A. Lauritzsen and T. Valstad of NGI, prof. L. Grande of NTH, G. Vefling and G. Jessen of COWIconsult, S. Holmberg of R&H and prof. J.M. Duncan of the University of Virginia.

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2.0 GENERAL DESCRIPTION

2.1 Program Identification

Program Name BEAST

Program Author Carl J. Frimann Clausen
Cidex 424 Bis
F-06330 Roquefort-les-Pins
Telephone (+33) (0)4 9377 5275
Telefax (+33) (0)4 9377 1979
E-mail cjfc@gf-net.com

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ABSTRACT

The program can be used to analyse slope stability, bearing capacity and earth pressure problems by a general procedure of slices. Total or effective stresses may be used. Shear surfaces may be planes, circles, combined surfaces or general surfaces specified point by point.

Different solution methods may be used. Some of these methods give force and moment equilibrium for each slice, with an automatic control of the quality of the solution obtained. The geometry considered is plane strain with inclusion of end surface shear stresses if wanted.

Program output includes computed safety factor or earth pressure, an indicator of the quality of the solution found, and detailed results of forces or stresses etc. for each individual slice. Plots of input data and computed results may be generated by BEAST or by a post processor program.

BEAST is written in FORTRAN-77. It is an interactive program and consists of approximately 12,000 program lines.

2.2 Program Capabilities and Limitations

Soil Properties

Each point within the soil volume is assigned a soil material identification number. For each soil material the unit weight is given, and in the case of total stress analysis :

* Undrained shear strength that may vary with the inclination of the shear surface.

In the case of effective stress analysis, the following values are required :

* Cohesion
* Angle of internal friction that may depend upon effective normal stress against the shear surface.
* Pore water pressure parameters (Ru,B,Ko,B2,D).

A general variation of undrained shear strengths and pore water pressures may be specified. An undrained effective stress analysis may be carried out, i.e. the pore water pressures are calculated during the iterative solution process.

A combination of effective and total stress analysis may be carried out, where the shear strength calculated using effective strength parameters is replaced by the given undrained shear strength, if the latter is the lower of the two.

Geometry

BEAST can handle two dimensional (plane strain) cases. Shear stresses at the end surfaces can be included if wanted. The soil surface is given as a broken line point by point. A rock surface may be specified at some depth below the soil surface. In case a shear surface intersects the rock surface, the shear surface is modified to follow the rock-soil interface. Zones of rigid material, e.g. a foundation block, may be specified. Shear surfaces that intersect such a zone are given a high safety factor.

A simple finite element type mesh is generated by BEAST to cover the soil body. This mesh may be used as a frame of reference for material properties, undrained strengths and pore water pressures. Alternative ways for quick and simple input of such values are available as well.

Shear Surfaces

The user may choose between the following alternative methods to generate the shear surface to be analysed :

* General surfaces specified point by point and read as a part of the input file. These surfaces may be shifted and/or stretched in the X- and Z-directions.
* Circles, either specified one by one, or generated by the program in an automatic search for the circle giving the lowest safety factor.
* Different types of combined surfaces consisting of straight lines - circles - straight lines, also with an automatic search facility.
* Straight lines (planes) in the case of active or passive earth pressure calculations.

Pore Water Pressures (PWP)

PWP values can be given by a number of different options, and combined to produce the wanted variation within the soil volume. Permanent matrix suction in fine-grained soils may be specified. Uplift and seepage forces, and the corresponding moments, are automatically computed once the PWP values have been found.

BEAST allows an undrained effective stress analysis (UESA) to be carried out. The PWP values are then calculated from effective stress changes and PWP parameters for each material type by an iterative solution process.

Given Loading

The system of slices may be subjected to the following types of loading :

* Self weight (vertical acceleration)
* Horizontal acceleration
* External free surface water pressures
* Internal water pressures (seepage forces)
* Given point forces (line loads)

* Given soil surface normal and shear stresses
* Loads imposed by piles and/or soil nails

Solution Procedure

BEAST is based upon limit equilibrium considerations, i.e. it is assumed that the design soil strength is fully mobilised along the entire shear surface. The program finds a solution that gives both force and moment equilibrium for each slice.

A solution of this type will always require that some assumptions are being made related to unknown values, for example the interslice roughness value or the position of the normal forces against the slice faces.

The present BEAST version (revision 4, April 2003) allows different solution methods to be used. These methods include force equilibrium with given interslice roughness, Bishop simplified, Bishop modified and a Morgenstern & Price type solution referred to as BEAST-2003.

When a solution has been obtained, BEAST will check the quality of this solution in terms of location of normal forces, interslice shear mobilisation etc. The results of this check is expressed as a "score". This allows BEAST to modify the assumptions made, repeat the analysis, and to find the solution with the best "score" value.

Instructions and Help to the User

Considerable efforts have been put into making BEAST a user friendly program. In order to reduce the need to consult the program documentation report, the INSTRUCTION and HELP facilities may be called upon during the interactive program operation.

This allows the user to display various types of information like explanation of error and warning messages, description of input file values etc., during the interactive program operation.

Program Output

BEAST generates summary type results that are displayed at the user's screen. Detailed print of selected shear surfaces, either the best one so far, or the last one analysed, may at any time be saved on a separate print file.

This print file may also include plots of input data (Su0 or PWP at mesh nodal points) and plots of computed values along the shear surface. Detailed results from a shear surface may be saved on another print file for later use by a post processing program.

Size Limitations

The present program version (April 2003) has the following limitations on the problem sizes that can be handled :

3500 elements and 3636 nodes in the FE type mesh used to assign properties.

101 vertical sections used to give the soil surface and the bedrock surface location.

50 different soil material types.

35 horizontal layers.

150 triangles used to assign soil properties.

25 vertical sections with given Su0 values with depth.

25 vertical sections with given PWP values with depth.

25 Su0 or PWP values at each vertical section.

50 given point forces.

20 strips with given distributed stresses.

30 general shear surfaces.

100 points on each general shear surface.

99 number of slices that each shear surface may be divided into.

75 piles and/or soil nails

The above values are set at the start of BEAST, and compared to the input values given. In case a limitation is exceeded, BEAST prints an error message and terminates the run. Procedures to be used in case these size limitations shall be changed, are given in Section 5.3.

2.3 Computer Requirements

BEAST is written in FORTRAN-77 and contains approximately 12,000 statements including comments. It needs 5 input/output files and a user's interactive terminal from which the program is operated. Terminal input/output is alphanumerical only, no graphic display unit is required.

Revision 3, 10 August 2000

The solution was extended to include piles and/or soil-nails. See Appendix D for a description of the procedures used. Soil matrix suction for different materials was introduced.

Revision 4, 24 April 2003

A number of new solution methods were included, i.e. force equilibrium, Bishop simplified, Bishop modified and BEAST-2003. The procedures used for the Swedish combined analysis have been completely re-written. The shear surface exit angle through frictional materials may automatically be reduced if needed. Materials with negative strength are used to flag the presence of rigid zones, e.g. a foundation base.

3.0 ENGINEERING DOCUMENTATION

3.1 Co-ordinate System and Units

BEAST uses an orthogonal co-ordinate system with a horizontal X-axis, positive either to the right or to the left, and with a vertical Z-axis that must be positive downwards.

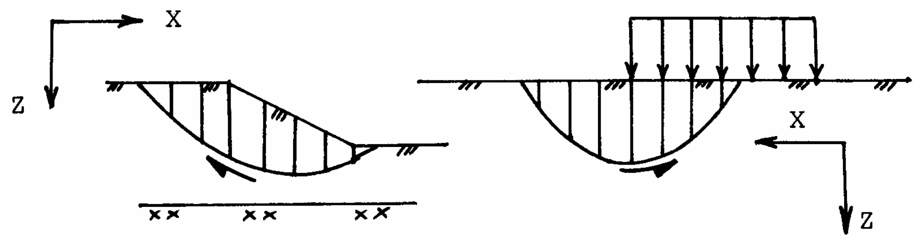


Figure 3.1.1 : Acceptable Co-ordinate Systems

The above figure gives examples of the two co-ordinate systems that may be used. Note that in both cases the horizontal displacement of the system of slices will be in the positive X direction.

At several places in this document reference is made to "right" and "left". Whenever these terms are used, it is assumed that the co-ordinate system is one with the positive X going from the left to the right.

BEAST will accept any system of units, it is the responsibility of the user to ensure that a consistent system is used. In order to allow program output in any system of units, independent of the input data units used, BEAST reads a length and a force multiplier at the start of the input data. All values are multiplied by these values immediately after they have been read from the formatted input file NF15.

Note that values read from the user's keyboard during the interactive program operation are **not** multiplied by these unit conversion factors.

3.2 Geometry Modelling and Shear Surfaces

The geometry of the plane strain system to be analysed is described by means of a number of vertical X-lines. At each of these lines the position of the soil surface and the rock surface is specified, together with instructions to BEAST on how detailed the finite element type mesh to be generated shall be. See Section 4.2 for detailed instructions and an example. Mesh nodal points and elements numbering system used is shown on Figure 3.3.2.

Each element in the generated mesh is given a material identification number. However, in order to allow easy specification of horizontal layering, and also to allow a completely general variation of material properties, the user may specify a number of horizontal layers and/or a number of triangles for which the material identification number is given.

Once the co-ordinates of any point (X,Z) is given, BEAST can thus find the material identification number at that point, and the corresponding soil properties. The detailed procedure used is explained at the start of Section 3.3.

With the main geometry known, BEAST needs a shear surface for which either stability/bearing capacity or earth pressure calculations shall be carried out. BEAST can handle the following types of shear surfaces :

* A straight line, for earth pressure calculations only.
* Circles.
* Combined surfaces consisting of straight line(s) and circle(s), Figure 4.3.1.
* General shear surfaces given as a broken line between specified points.

The three first types of surfaces are generated by BEAST from data given via the user's keyboard. General shear surfaces are read from the input data file NF15.

With the co-ordinates of points along the shear surface known, BEAST finds the two first intersections between the shear surface and the soil surface. If a geometry problem is identified, an error message is printed and the run terminated.

The body of soil enclosed by the shear surface and the soil surface may now be divided into the number of slices specified by the user. Under normal conditions equal width of all slices is used. However, in the case of general shear surfaces, the user may specify that a slice division correspon-ding to the given points on the general shear surface shall be used.

BEAST will automatically generate extra slices when the shear surface intersects horizontal layer interfaces. This is done to avoid having two different materials at the slice bottom.

The geometry of the system to be analysed has now been established. Next step will be to assign soil property values to the different points in the system, and to compute all values that are independent of the factor of safety.

Figure 3.2.1 below shows a typical slice with the corner point numbering and face numbering system that is used by BEAST. The centre point 5 is found as the centre of gravity of the slice.

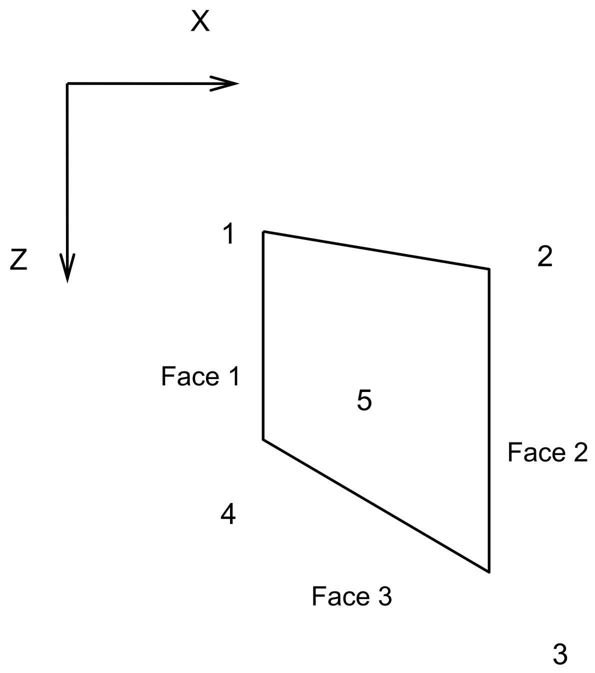


Figure 3.2.1 : Slice Corner Point and Face Numbering System.

3.3 Soil Properties

A given point (X,Z) is assigned a material identification number by the following steps :

1. Find the mesh element number that the point falls inside, and give the point the material number assigned to that element.
2. If horizontal layers were specified, replace the above by the material number corresponding to the layer inside which the point falls.
3. If material triangles were specified, and the point falls inside or on the side line of such a triangle, replace the above by the material number corresponding to the **first** triangle inside which the point falls.

For each material a complete set of soil parameters, to be used for both total and effective stress analysis, has been given as part of the input data read from file NF15. These soil property values are described in detail below.

Total Unit Weight

The unit weights given are assumed to be total values, i.e. they include weight of both soil particles and water. For a system completely submerged in water the effective unit weights may be used, provided the hydrostatic pore water pressure (PWP) is set to zero. See next section for more details.

Undrained Shear Strengths

BEAST allows the user to specify any variation of undrained shear strength (Su) values in the horizontal and the vertical direction. These Su values may either be isotropic, i.e. independent of the inclination of the shear surface, or anisotropic values corresponding to +45,0,-45 degrees shear surface inclination may be specified, see Figure 3.3.1.

For each material the three ratios SuA/Su0, SuD/Su0 and SuP/Su0 are given. With known Su0 (see below) and material id. the anisotropic Su values corresponding to active triaxial, direct simple shear and passive triaxial (ADP) can then be computed.

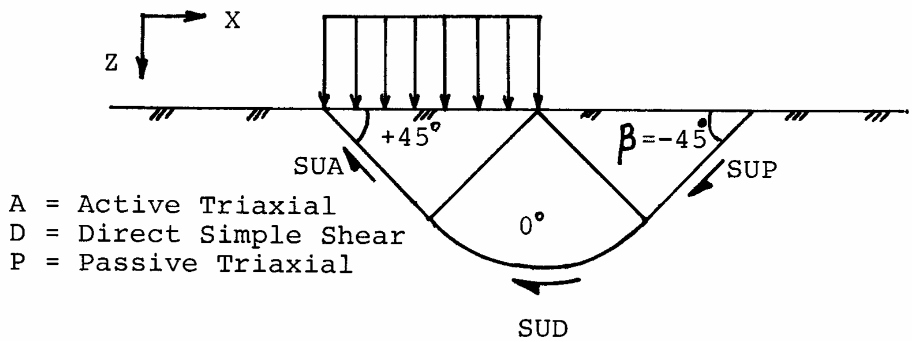


Figure 3.3.1 : Undrained Shear Strength Depends Upon Shear Surface Inclination.

For a general value of the shear surface inclination BETA the following interpolation formula is used :

Su(BETA) = SuD + (SuA - SuD)*sin(2BETA) , BETA > 0.0 (3.3.1)

Su(BETA) = SuD - (SuP - SuD)*sin(2BETA) , BETA < 0.0 (3.3.2)

The basic Su0 values can be given by 3 different methods :

1. Given as a constant value for each material.
2. Given as a broken line with depth at vertical X sections.
3. Given as values at the nodal points of the mesh.

For each point (X,Z) the resulting Su0 value is taken as the sum of these three values. When values at nodes are to be included, a weighted average of the element nodal point values is used as shown on Figure 3.3.2 below.

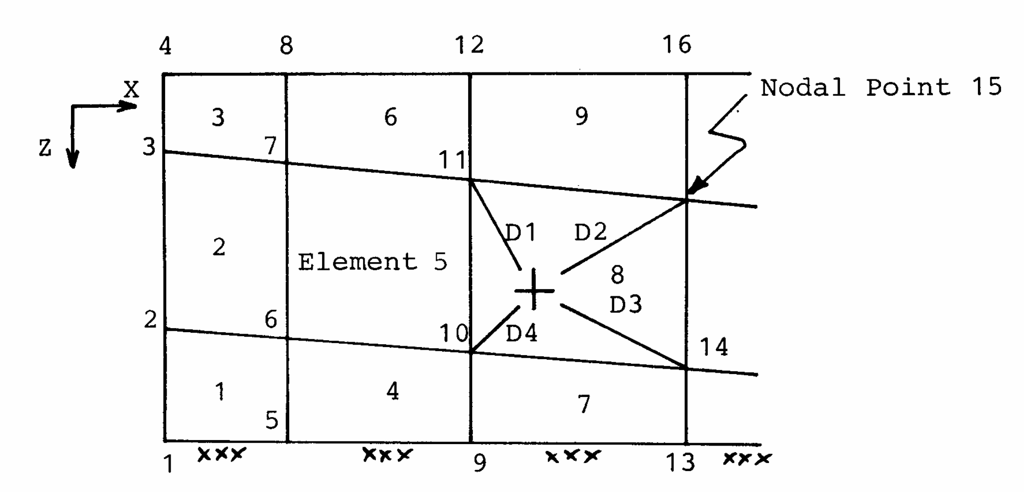


Figure 3.3.2 : Mesh Numbering and Procedure for Weighted Average of Values Specified at Nodal Points.

The weighted average at point (X,Z) is found as :

$$DIV = 1/D1^2 + 1/D2^2 + 1/D3^2 + 1/D4^2 \quad (3.3.3)$$

$$Su0(X,Z) = (Su0(11)/D1^2 + Su0(15)/D2^2 + Su0(14)/D3^2 + Su0(10)/D4^2) / DIV \quad (3.3.4)$$

where D is the distance from the point (X,Z) to the nodal point considered.

Cohesion

The cohesion value c given for each material is used in the Mohr-Coulomb expression for the failure shear stress τ :

$$\tau = c + \sigma' \cdot \tan(\varphi') \quad (3.3.5)$$

where σ' is the effective normal stress on the shear surface and φ' is the effective angle of internal friction.

The c value is assumed to be isotropic, i.e. independent of shear plane inclination.

One may want to analyse cases with both sand and clay layers on an effective stress basis, but to maintain the anisotropic ADP type undrained shear strengths explained above for clay layers. In order to allow this, BEAST will check if cohesion and friction are both zero. In that case, the cohesion is replaced by the Su(BETA) value found above, and the friction angle maintained as zero.

Angles of Internal Friction

An angle of internal friction, PHIANG, is read for each material. In addition, the user may specify two values, PHIREF and PHIRED, to model a friction angle that depends upon the effective normal stress SIG :

PHI(SIG) = PHIANG - PHIRED*Log10(SIG/PHIREF) (3.3.6)

The PHI angle is directly used by BEAST in the plane strain type calculations carried out. Any possible modification of a laboratory triaxial angle of internal friction to account for plane strain effects is the responsibility of the user.

Parameters for Undrained Effective Stress Analysis (UESA)

BEAST may carry out an undrained effective stress analysis, i.e. the excess pore water pressures are to be calculated as a part of the solution. Appendix B gives the theoretical basis for this analysis.

In order to allow such calculations, the following soil parameters are needed for each material :

* B-FACTOR : DEL.U = B * (DEL.SIGAVR - D * DEL.SIGDEV) (3.3.7)
* K-NOT : Initial effective stress ratio SIG30/SIG10
* B-SIG2 : Intermediate principal stress ratio , SIG2 = SIG3 + B * (SIG1 - SIG3) (3.3.8)
* D-FACTOR : Shear contribution to DEL.U, equation (3.3.7) above.

For real soils the D-factor will in general not be a material constant, but depend upon stress level and direction of stress changes. BEAST therefore allows specified Su0 values, multiplied with SuADP ratios, to be interpreted as D-factors.

Rigid Materials

The soils in a slope or near a foundation may contain strong structural elements like a wall or a concrete base. The presence of such obstructions may be modelled by the rigid material option. If a material is given a negative strength, for example Su = -50 kPa or φ' = -25°, shear surfaces that cut through such a material gets a safety factor of 99.999 and a score of 7.777. Such surfaces thus become non-critical. The interslice strength is found using the absolute value of the soil strength parameters, and the negative value has no effect.

Soil Properties Used by BEAST

The above explained how soil properties are obtained at a single given point (X,Z). For each slice we need average values along the faces 1, 2 and 3, see Figure 3.2.1.

At face 3, the shear surface, the strength values (tan φ', c and Su) are found as the average of the values determined in 5 points along the slice bottom.

At face 2 (which is face 1 for next slice), the value is found as :

V avr = (V2 + 2*V23 + V3) / 4.0 (3.3.9)

where V2 and V3 are values at top and bottom of face 2, and V23 is the value at mid height. It should be noted that this averaging procedure may influence the computed results in the case of several layers with very different properties.

3.4 Pore Water Pressures and Forces

BEAST has a number of different options that can be used to generate PWP values at any point within or at the surface of the soil body considered. Figure 3.4.1 illustrates the different options, and they are explained in some detail below.

Hydrostatic Pore Water Pressures

In order to simplify program input and to save computer time, the user specifies if the PWP is hydrostatic or not. If hydrostatic conditions are specified, the PWP is computed as :

$$PWP = (Z - WT) * GAMWAT \qquad (3.4.1)$$

where Z is the Z co-ordinate of the point, WT is the Z co-ordinate of the water table and GAMWAT is the unit weight of water.

The PWP input data includes the minimum allowed PWP value (could be negative as a result of capillary tension, referred to as matrix suction below). If the PWP value found by equation (3.4.1) or by the below non hydrostatic procedures, is lower than this minimum, the minimum is used. For non-hydrostatic pore pressures the minimum PWP value may be multiplied by a material dependent factor, see Option E below.

Non-Hydrostatic Pore Water Pressures

In case the user has specified non-hydrostatic PWP, BEAST will run through all possible options and add the individual contributions found, with the exceptions explained at the end of this section.

Option A : Given PWP With Depth at Vertical Sections

This option may in principle be used to specify any variation of PWP. The user gives the position of a number of vertical profiles (X-lines). The PWP variation with depth at each profile is given point by point. For any point (X,Z) BEAST will then determine the PWP value by linear interpolation or extra-polation.

When the given point (X,Z) is located between two profiles, as shown on Figure 3.4.1, interpolation is carried out along a line parallel to the line that connects the two top points in each profile.

For points located before the first X-line, or after the last X-line, interpolation is done along a horizontal line.

Points above or below the first or the last point on the X-line are given PWP values equal to the first or the last value.

Option B : PWP as a Ratio of Total Overburden

This way of giving PWP is often used in connection with dams and embankments. For a given point (X,Z) BEAST first determines the material identification number, Section 3.3, and the corresponding value of Ru. The PWP value is then computed as :

$$PWP = Ru * (Z - ZSURF) * GAM \qquad (3.4.2)$$

where ZSURF is soil surface Z-level at X and GAM is the average unit weight, taken at mid height.

It should be noted that BEAST will interpret a negative Ru value to mean that PWP shall still be computed from equation (3.4.2), with changed sign. However, none of the other options A,C,D,E or F shall be included. Such a procedure may be needed for example in the case of a dam with a clay core.

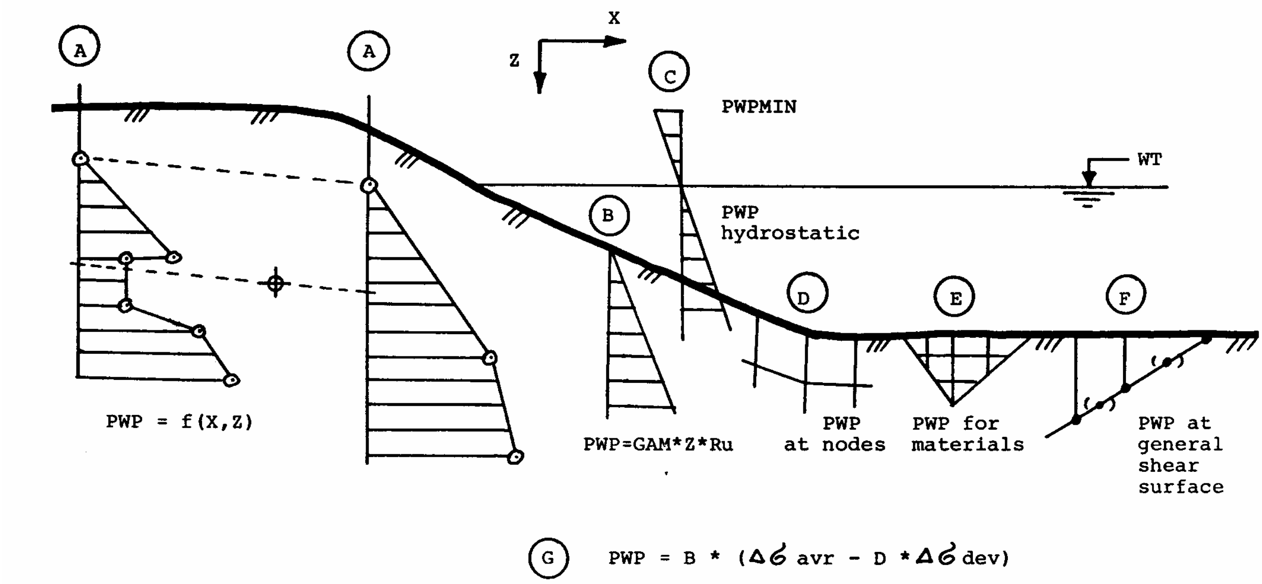


Figure 3.4.1 : Different Options That May be Used to Specify Pore Water Pressures

Option C : Given PWP Unit Weight

This option assumes a linear variation with depth with zero PWP at the Z-level of the given water table.

If the soil surface above the point (X,Z) is not submerged, the PWP value is computed as :

$$PWP = (Z - WT) * GAMPWP \tag{3.4.3}$$

where WT is the water table level and GAMPWP is the pore water given unit weight.

If the soil surface point is submerged, i.e. ZSURF is greater than WT, the PWP is computed as :

$$PWP = (ZSURF - WT) * GAMWAT + (Z - ZSURF) * GAMPWP \tag{3.4.4}$$

where ZSURF is the soil surface Z level above the point and GAMWAT is the given unit weight of water.

This option C will not be used if option A is specified, as option C could give a problem for cases with water on one side only. BEAST assumes that the specified water table extends over the entire system at the same Z level. If this assumption shall not be made, PWPs must be specified by option A, and BEAST will calculate the corresponding ground water levels, and use these values for load calculations.

Option D : PWP Values Given at Mesh Nodal Points

This option will in principle allow any variation of the PWP, provided a sufficiently fine mesh is generated. The nodal point PWP values are read from input file NF15. Procedures used to compute a weighted average value at point (X,Z) are identical to those described for undrained shear strength in Section 3.3 above.

Option E : PWP Values Specified for Soil Material

Each material has been given a PWP value that is associated with that material only. Under most conditions the value would be zero. However, the option may be used to describe a certain layer or an area that is charged with PWP values different from those in the surrounding soil volume.

The user may want to specify different minimum allowed PWP values for the different materials, for example in a slope stability analysis where matrix suction shall be included in silts but not in sands. Analyses of this type are described by Öberg (1997) and SGI (1998). The D-parameter read as input may be used for this purpose as described in Section 4.2.

Option F : PWP Values Specified for General Shear Surfaces

If the user has specified non-hydrostatic PWP values, and if general shear surface(s) shall be read as input, BEAST expects to find PWP values for each surface together with the co-ordinate values. This option allows an easy input of PWP values along a pre-determined shear surface. The specified values will be added to the PWP values computed from any of the above options.

Option G : UESA, Undrained Effective Stress Analysis

BEAST allows an undrained effective stress analysis to be carried out, see Svanø (1981) and Svanø & Nordal (1988) for a description of the principles of the method.

In this case the PWP values are not explicitly given, but they are calculated from stress changes along the shear surface. Stress changes and PWP changes are assumed linked by the following equation, Janbu (1979) :

DEL.U = B * (DEL.SIGavr - D * DEL.SIGdev) (3.4.5)

The B- and D-parameters are given for each material. BEAST allows the D-parameter to depend upon inclination of the shear plane. Details of assumptions involved and solution procedure are given in Appendix B.

Combination of Different PWP Options

The above will allow any variation of PWP to be modelled by the user. If non-hydrostatic PWP was specified, the main rule is that each PWP contribution is calculated and added to the others to form the resulting PWP. However, the following exceptions from this rule exist :

1. A negative Ru value for a material is used to flag that Ru contributions only are to be included for that material.

2. If PWP values at vertical X lines were specified, PWP values calculated by option C (given PWP and water unit weights) are not included. This allows different water levels at two sides of an embankment to be modelled.

3. In case of UESA, all other PWP contributions are set to zero, for all materials.

Pore Water Pressure Forces

The above can be used to find the resulting PWP at any point (X,Z). What is needed below is the resulting PWP force acting against the three slice faces 1, 2 and 3 shown on Figure 3.2.1.

In the case of hydrostatic PWP, the corresponding forces against the faces, and the points where they act, can be computed exactly.

In the case of non-hydrostatic PWP, an approximate numerical integration must be carried out. BEAST computes the PWP values in 5 points along face 3 at the slice bottom (shear surface), and in 10 points along face 2 (interslice vertical contact surface).

3.5 Load Calculation

Each slice may be subjected to the following types of forces, that will be independent of the safety factor :

* Vertical and horizontal self weight forces.
* Forces due to given external line loads and distributed stresses.
* Water pressures against the top of the slice and in cracks.
* PWP forces against slice faces 1, 2 and 3.
* Side shear forces in case a non plane strain situation shall be simulated, calculated initially with safety factor = 1.0.
* Axial and lateral soil nail forces, calculated initially with safety factor = 1.0.

Self Weight Forces

The area of each slice is computed assuming a straight soil surface between the two top points 1 and 2, Figure 3.2.1. If a broken soil surface line exists over the slice width, an approximate correction is carried out.

If more than one material is specified, an accurate average unit weight is calculated for each slice in the case of horizontal layering.

If material triangles are used, or zero horizontal layers were specified, the average unit weight is determined by a numerical summation with 10 X increments and 30 Z increments for each slice.

The vertical force acting through the slice centre 5 is then found as :

WZ = AREA * GAMAVR * ACCZRT (3.5.2)

where AREA is slice area and ACCZRT is an acceleration ratio, equal to 1.0 if normal gravity acts. In the same manner, the horizontal force through point 5 is computed as :

WX = AREA * GAMAVR * ACCXRT (3.5.3)

where ACCXRT is the acceleration ratio in the X-direction, equal to 0.0 unless earthquake type loading shall be included.

Given External Line Loads and Stresses

External line loads may act vertically and horizontally, and at any point within or above or below the soil volume considered. For each slice line loads located at a vertical line within the slice are included, even if the line load is acting above the soil surface. However, line loads located underneath the shear surface are not included.

Distributed stresses are assumed to act at the soil surface. For each slice an exact computation of forces and moments is carried out, even if discontinuities exist over the slice.

Water Pressures on Top of Slice and in Cracks

An exact calculation of water pressure forces and moments is carried out for each slice based upon slice points 1 and 2 co-ordinates, water table and water unit weight. If vertical sections with PWP values were specified, the water table elevation above each slice (may vary along the profile) is calculated from these values.

At the first slice a crack may exist on the left side. The depth of such a crack, and the depth of water in the crack, is part of the input data. The procedure used by BEAST to handle such cracks is shown on Figure 3.5.1. The starting point of the shear surface is moved from point 4 to point 4'.

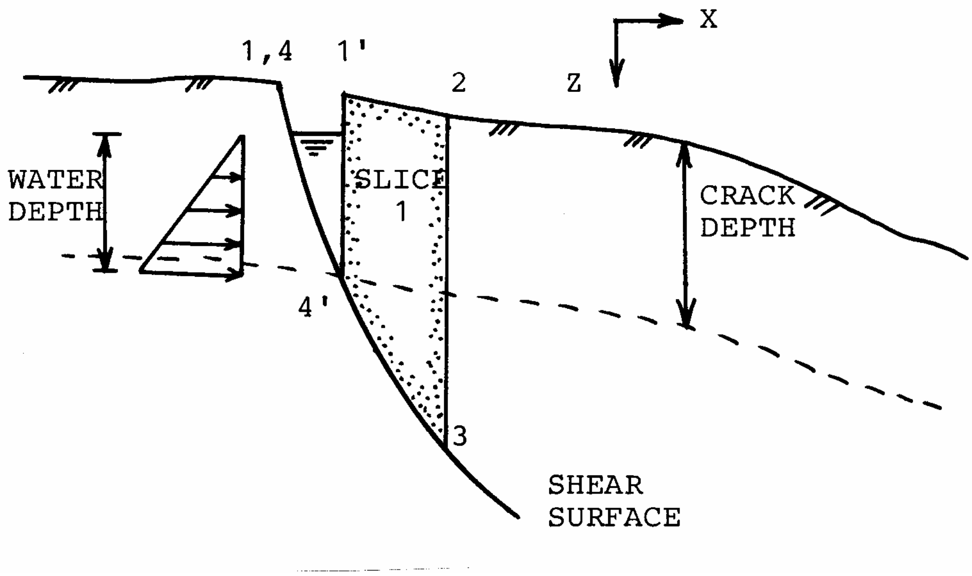


Figure 3.5.1 : Procedure Used to Include Cracks and Water in Cracks.

PWP Forces

Methods used to compute these forces were described in Section 3.4. They enter the computations just like the other forces described above, and are summed together with them at slice centre point 5. This results in two known forces WX and WZ, acting through point 5, and one moment WM.

In the case of UESA, the PWP forces are found by an iterative procedure as described in Appendix B.

Side Shear Forces

In case the system analysed has limited length normal to the paper plane (Y-direction), the user may want to include a correction to account for the shear forces that may act upon the two side (end) surfaces. Assuming a safety factor of 1.0, BEAST finds the side shear force at each slice by the following procedure :

1. Compute the average effective unit weight of the slice from the total unit weight at the slice centre point 5 and the water table level.
2. Compute average horizontal stress SIGH in the Y- direction assuming Ko' = 0.5.
3. Compute force FY as SIGH * AREA
4. Compute side shear force SS as :

SS = (C2*AREA + FY*tan(PHI2)) * SIDSHR (3.5.4)

where C2 is cohesion or undrained strength at slice face 2, PHI2 is the friction angle at face 2 and SIDSHR is a factor given as input.

All forces in BEAST are computed assuming a unit length in the Y-direction. If, as an example, the system analysed has a length of 25 m in the Y-direction, and we want to include full side shear at both end surfaces, the value of SIDSHR should be given as :

SIDSHR = 2.0 / 25.0 = 0.08 (3.5.5)

This option should be used with care in connection with shallow footings on sand subjected to mainly vertical loading, as a positive SIDSHR will always increase the safety factor, whereas reality may be the opposite.

The side shear force SS is assumed to act through the mid-point between the shear surface and point no. 5. Its direction is assumed parallel to the shear surface, and it is always acting against the displacements. When the system of slices is being solved, the above shear force SS is divided by the safety factor.

Soil Nail Forces

Forces from piles and/or soil nails were included in revision 3 of the BEAST program. The procedures used to calculate the axial and the lateral soil nail forces are described in some detail in Appendix D. These values are first calculated assuming a safety factor of 1.0 on soil skin friction and on the structural strength. During the iterative solution of the system of slices, the pile/nail forces are divided by the same assumed safety factor as the one used on the soil strengths, and included in the equilibrium equations.

3.6 Governing Equations

Figure 3.6.1 shows a typical slice with the forces acting upon it, and the locations of these forces. The pore water pressure forces U1, U2 and U3 (and their locations) are calculated in advance from the pore water pressures found as described in Section 3.4. These forces are then included in WX, WZ and WM acting at the slice centre point 5.

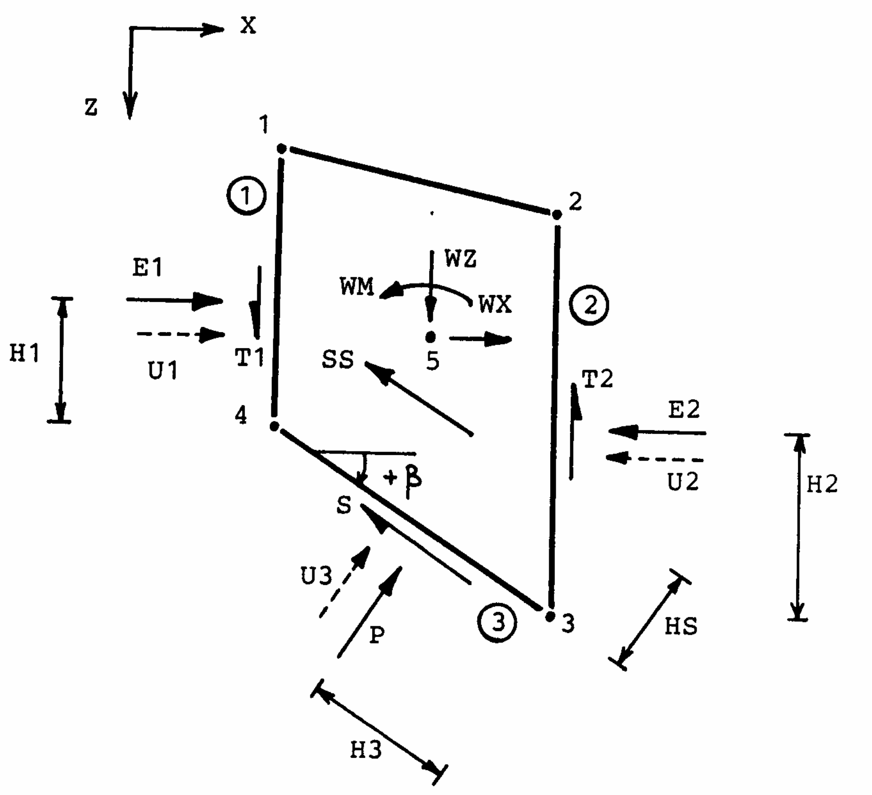


Figure 3.6.1 : Single Slice With Forces and Moment Arms.

The values shown are :

E1, E2, P	Effective normal forces.
T1, T2, S	Shear forces.
WX, WZ, WM	Known forces and moments referred to the slice centre. Includes self weight, given external loading and pore water pressures.
SS	Side shear force.
H1, H2, H3	Location of normal forces.
HS	Location of side shear force.
BETA	Shear surface inclination.

All values are positive when acting as shown on Figure 3.6.1.

The forces shown on Figure 3.6.1, and also the equations (3.6.1) to (3.6.14) shown below, do not for reasons of simplicity include the forces from piles/soil nails. Appendix D explains how such forces are taken into account and presents the corrected equations that are actually used in the calculations.

Program BEAST solves a system of slices from the left to the right (increasing X-value) with an assumed or a known factor of safety. At the first slice, E1 and T1 will always be zero, any known forces acting here would be included in WX, WZ and WM.

After a slice has been solved, we know all the above values. This means that E1, T1 and H1 for the next slice are also known, as they must equal E2, T2 and H2 for the present slice. We can therefore write the following table of known/unknown geometry and forces for a single slice :

Table 3.6.1 : Single slice known and unknown values

	Known	Unknown
Geometry :	H1,HS	H2, H3
Forces :	E1, T1, SS WX, WZ, WM	E2,T2 P, S

For each slice we can write 3 equations related to equilibrium and 1 equation for failure shear stress at the shear surface :

Sum X-forces = 0.0

E1 + WX - E2 + P * sin(BETA) - (S+SS) * cos(BETA) = 0 (3.6.1)

Sum Z-forces = 0.0

T1 + WZ - T2 - P * cos(BETA) - (S+SS) * sin(BETA) = 0 (3.6.2)

Sum moments w.r.t. point 3 = 0.0

B = X2-X1, H4 = Z3-Z4, B5 = X3-X5, H5 = Z3-Z5

T1 * B - E1 * (H1+H4) + WM + WZ * B5 - WX * H5 + SS * HS + E2 * H2 - P * H3 = 0 (3.6.3)

Fully mobilised shear strength at face 3

S = (C3 * L34 + P * tan(PHI3)) / SF (3.6.4)

where SF is the assumed or known safety factor, C3 the cohesion at face 3, PHI3 the friction angle at face 3 and L34 the shear surface length.

For the unknown shear force T2 we can write an equation similar to (3.6.4) :

T2 = R * (C2 * L23 + E2 * tan(PHI2)) / SF (3.6.5)

where R is an unknown roughness value between -1.0 and +1.0.

If the two shear force equations are introduced into the three equilibrium equations, we obtain after some simple arithmetic :

Sum X : P*C11 - E2 = C12
(3.6.6)

Sum Z : P*C21 + R*E2*tan(PHI2)/SF + R*C22 = C23 (3.6.7)

Sum M : P*H3 - E2*H2 = C31 (3.6.8)

The C-coefficients are given by :

C11 = sin(BETA) - tan(PHI3)*cos(BETA)/SF (3.6.9)

C12 = -E1-WX+SS*cos(BETA)/SF+C3*L34*cos(BETA)/SF (3.6.10)

C21 = cos(BETA) + tan(PHI3)*sin(BETA)/SF (3.6.11)

C22 = C2*L23/SF (3.6.12)

C23 = T1+WZ-SS*sin(BETA)/SF-C3*L34*sin(BETA)/SF (3.6.13)

C31 = T1*B - E1*(H1+H4) + WM + WZ*B5 - WX*H5 + SS*HS/SF (3.6.14)

The 3 equations (3.6.6 to 3.6.8) are the governing equations for any system of slices. The only assumptions made so far are :

1. The Mohr-Coulomb failure criterion applies, equations (3.6.4) and (3.6.5).
2. The factor of safety is constant through the system of slices.

It is seen that the 3 equations contain the following unknowns : P, E2, R, H2 and H3, i.e. 5 values. In order to solve this system one must therefore make 2 assumptions. It must be expected that it will be easier to guess geometry constants H2 and H3, and interslice roughness R, rather than actual forces P and E2. Three main possibilities therefore seem to exist :

A. Assume H2 and H3, compute R and forces.
B. Assume H3 and R, compute H2 and forces.
C. Assume H2 and R, compute H3 and forces.

The well known procedures by Morgenstern and Price (1965), and Spencer (1967), are of type B. The generalised procedure of slices first published by Janbu (1957,1973) is in principle of type C. However, the interslice shear force T, rather than the roughness R, is "assumed" by Janbu, i.e. calculated from moment equilibrium of the vertical interface between two slices.

Other procedures, like Fellenius (1927) and Bishop (1955) may fall outside this system, as these procedures do not satisfy all the equilibrium requirements. The reader may want to consult Wright (1969) for a detailed description of such procedures and the associated assumptions.

BEAST Revision 2

After several years of experience with the BEAST program it was seen that the selected type B solution procedure now and then gave problems related to non-convergence and solution score (see Section 3.9). It was therefore decided to adapt a somewhat modified solution technique as described in Section E4 of Appendix E.

3.7 Solution Procedures, Stability and Bearing Capacity

Revision 4 of program BEAST may use five different solution methods. The governing equations and procedures used for each of these methods are described in Appendix E.

These methods all involve a potential numerical problem. In order to determine the P-force against the slice bottom, a division must be carried out, and the divisor could be zero or negative, depending upon shear surface geometry and soil properties. This potential problem is discussed below, followed by comments related to (1) the BEAST simplified total stress solution for circles, (2) the Swedish combined analysis method, and (3) a summary of the BEAST revision 4 extensions.

Potential Numerical Problem

With an assumed value of the safety factor SF, we can calculate the coefficients C11 to C31 from equations (3.6.9) to (3.6.14). Combining equations (3.6.6) and (3.6.7) gives :

DIV = C21 + R*tan(PHI2)*C11/SF (3.7.1)

P*DIV = C23 + R*(tan(PHI2)*C12/SF - C22) (3.7.2)

Having found the P force, the two remaining unknowns are calculated from :

E2 = P*C11 - C12 (3.7.3)

H2 = (P*H3 - C31) / E2 (3.7.4)

For slope stability and bearing capacity problems the force E2 shall be zero at the last slice. After the first pass through the system with an assumed SF, it will therefore be necessary to repeat the process with other SF assumptions until the E2 force becomes smaller than a user defined convergence criterion.

In the case of total stress analysis it is found that the E2 force at the last slice can be expressed as :

E2 = E2LIM - AA / SF (3.7.5)

E2LIM = SUM(WX + WZ*tan(BETA)) (3.7.6)

In the case of effective stress analysis there is a more complex relationship between E2 at the last slice and SF. During the iterative solution process care must therefore be taken to obtain the first solution E2 = 0.0 as SF is decremented. Figure 3.7.1 shows an example of calculated relationship between SF and E2. It is seen that discontinuities exist when SF is lower than say 0.85 for the example shown on the figure.

What happens is a zero division when calculating P from equation (3.7.2). We have that :

DIV = C21 + R*tan(PHI2)*C11/SF (3.7.6a)

Taking C11 and C21 from (3.6.9) and (3.6.11) we obtain :

DIV = 1 + tan(PHI3)*tan(BETA)/SF + R*tan(PHI2)*(tan(BETA) - tan(PHI3)/SF)/SF (3.7.7)

For the example shown on Figure 3.7.1 we have :

BETA = 45 - PHI/2 = 27.5 degrees (3.7.8)

tan(PHI2)/SF = tan(PHI3)/SF = tan35/0.85 = 0.82 (3.7.9)

DIV = 0.57 - R * 1.10 (3.7.10)

DIV thus becomes zero and then negative when R is 0.52 or higher.

The above demonstrates that in any limit equilibrium procedure it will be necessary to ensure that the shear surface inclination in the passive zone is compatible with the friction angles PHI2 and PHI3, and the interslice roughness factor R. In revision 4 of BEAST an option was therefore included that allows an automatic reduction of a too steep shear surface exit angle.

Using the above expressions, the initial distribution of the P-forces is established. BEAST may then modify this solution by the procedures explained in Section E4 of Appendix E, and calculate all unknown forces, moment arms and interslice roughness values.

We then have a complete solution, and we can inspect the solution in order to determine its quality. Such an inspection is done automatically by BEAST and the result expressed as a single number referred to as "score". Score equal to zero means that the solution meets all quality requirements. The higher the score value, the poorer the solution. The method used by BEAST to calculate the score value is explained in detail in Section 3.9 below.

The score concept allows BEAST to try different assumptions for the interslice roughness factor R, calculate the SF and the score value, and to select as final solution the R assumption that gives the lowest score value. The R assumptions tried by BEAST are the initial Ro values specified by the user multiplied by factors that will cover the range R = 0.0 to 1.0.

In case several R assumptions all lead to zero score, BEAST takes the solution with the highest safety factor as the wanted solution.

From the above it follows that the moment equilibrium equation for each individual slice (3.6.8) is only used indirectly, i.e. to find the position H2 of the line of thrust which will influence the calculated score value. For the last slice the moment equation is used to calculate H3 rather than H2.

Simplified Solution, Circles and Total Stresses

For cases that involve both circular shear surfaces, and total stress analysis, BEAST will use a simplified solution method that only considers moment equilibrium.

The area of the slices, and the shear surface lengths, are increased to include the small circle segment underneath the shear surface. Undrained strengths at the shear surface, slice centre forces etc. are calculated by the standard BEAST procedures as explained in this report.

After the safety factor is found, all slice forces except S are set to zero. The score value for these solutions is set to 9.999.

Swedish Combined Analysis, BEAST Revision 3

Analysis of slope stability and bearing capacity has traditionally been carried out as either effective stress analysis, or as a total stress analysis. It may be argued that a slope stability analysis should be carried out as a combination of the two methods, where the lowest strength obtained by the two analyses at any point is used, see for example Sällfors & Larsson (1984).

BEAST allows this type of analysis to be carried out. For the given shear surface an effective stress force equilibrium solution is established with the given roughness values. With known P and E2 normal forces the corresponding shear strengths can be calculated from equations (3.6.4) and (3.6.5). These shear strengths are then compared to the given undrained strength values. If the undrained strength values are lower, the cohesion at that face is replaced by the undrained strength, and the friction set to zero.

A normal BEAST effective stress analysis is then carried out using the modified strength values.

BEAST Revision 4

This revision was made primarily because of small errors that now and then occurred for the combined analysis. The combined analysis method compares the effective stress based and the total stress based shear strengths at the slice bottom, and uses the smaller value. A combined analysis solution should therefore always give a safety factor that is equal to, or lower than, the safety factors from the effective stress and the total stress solutions. Unfortunately, this was not always the case for BEAST revision 3.

It was therefore decided to completely re-write the BEAST combined analysis procedures. This provided an opportunity to also expand and improve the solution methods that could be used by BEAST. These revised procedures are described in the new Appendix E.

At the same time it was decided to also include :

* A rigid material option that may be used to model the presence of e.g. a foundation base. Shear surfaces that intersect a zone with a rigid material are given a safety factor of 99.999 and a solution score (see below) of 7.777.

* An option that allows BEAST to automatically reduce the shear surface exit angle through frictional materials. This option is explained in Section 4.2 of the report.

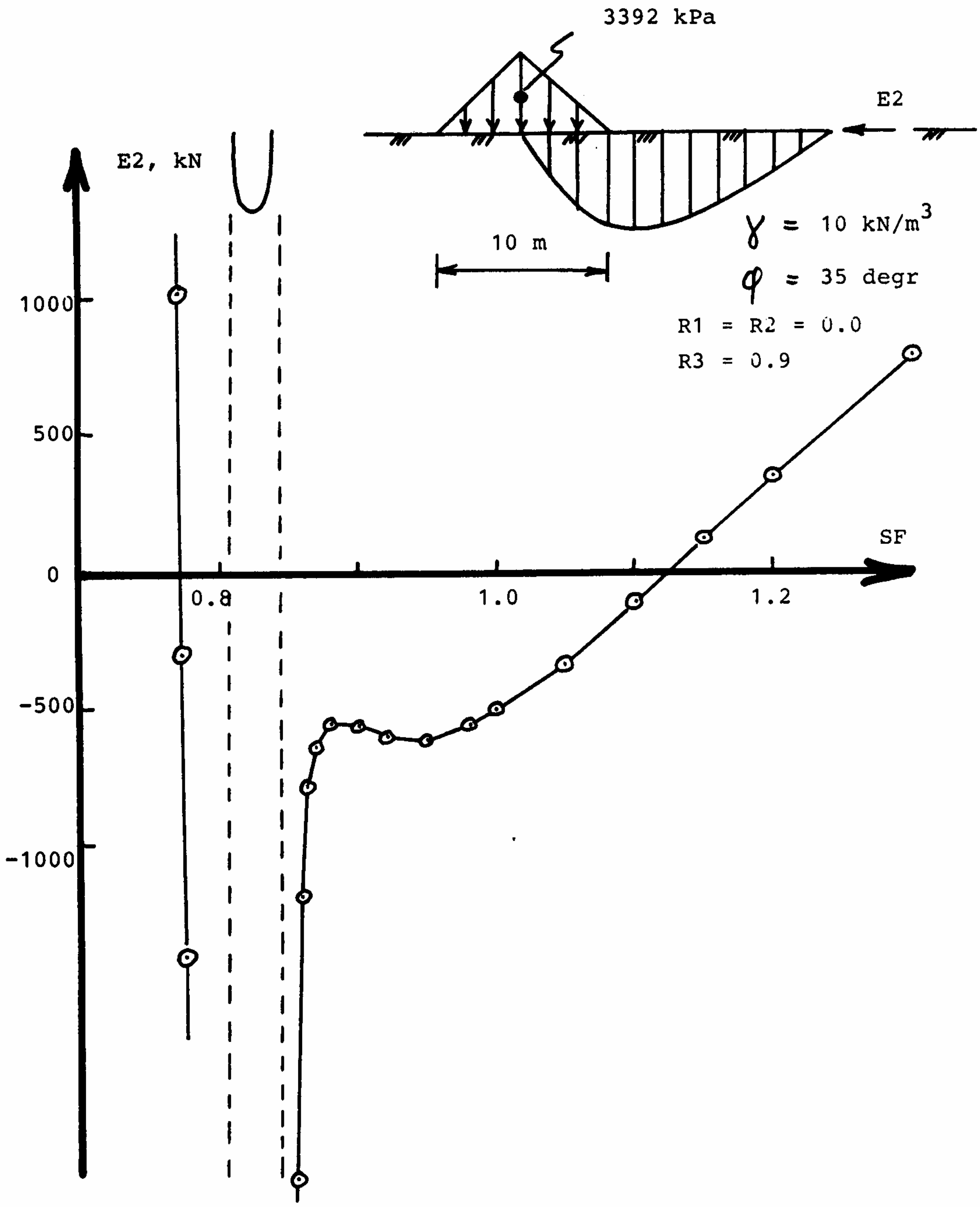


Figure 3.7.1 : Example Relationship Between Assumed Safety Factor SF and Horizontal Force E2 at the Last Slice.

3.8 Solution Procedures, Earth Pressures

Earth pressure calculations can be handled by procedures very similar to those used for slope stability and bearing capacity calculations, as pointed out by Nilmar Janbu already some 45 years ago, Janbu (1957).

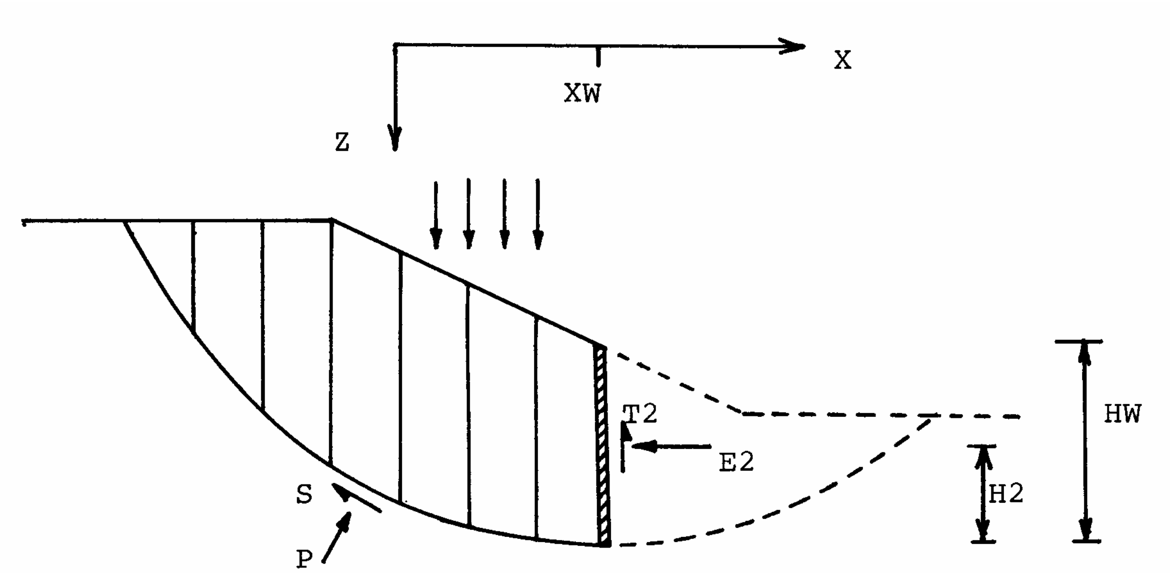


Figure 3.8.1 : Earth Pressure Calculations

As part of the input data read by BEAST, the user specifies if bearing capacity or earth pressure calculations shall be carried out. BEAST also reads the location of the wall, XW, the height of the wall, HW, and the wall roughness (relative magnitude and sign of the shear force T2).

Earth pressure calculations are carried out with the same basic assumptions as described for stability and bearing capacity cases in Section 3.7. This means that the position H3 of the normal force P on the bottom of the slice is known, together with the interslice roughness R. BEAST assumes a linear variation of R from R1 at the start of the shear surface to RW at the wall itself. R1 and RW are user supplied values.

For a given shear surface BEAST then only needs a safety factor (to be specified by the user) in order to compute through the system of slices, and end up with the corresponding earth pressure values E2, T2 and H2 as shown on Figure 3.8.1.

If a **positive** safety factor is specified, the E2 force computed will be the **active** earth pressure, which is the situation shown on Figure 3.8.1. If a **negative** safety factor is specified, all shear forces S, SS and T will act in the opposite direction, and the E2 force computed will be the **passive** earth pressure.

3.9 Solution Quality Control

Once a solution has been obtained, BEAST carries out a fairly detailed check for two reasons :

1. To identify obvious errors or problems and present an error message to the user.
2. To find a measure for the quality of the solution, i.e. how close it is to what one would consider as a "perfect" solution.

Error Messages

The checks carried out by BEAST include :

* Check that P and S forces at each slice bottom really gives a degree of strength mobilisation equal to the computed safety factor.
* Check that the three equilibrium requirements are satisfied for each slice.
* Check that computed forces E2 and T2 at last slice are zero for stability and bearing capacity cases.

The above checks should not really be necessary, as the requirements are part of the equations solved. However, programming errors or other unintended conditions could lead to results that do not meet the above requirements.

Solution Quality, Score

The above checks are aimed at solution errors and results that are obviously wrong. Even if a solution passes these checks, the solution quality may still be rather poor. We therefore need a system by which it is possible to find a single number that reflects how near the present solution is to what we would consider a "perfect" solution.

For this purpose BEAST operates with a value called "score". Score = 0.0 is considered to be a perfect solution that has the following qualities :

1. All normal forces P and E2 are positive. Negative values may be specified as allowed.
2 The interslice degree of shear mobilisation R is between +1.00 and -1.00.
3. The normal force P acts within the middle third of face 3.
4. The normal force E2 acts within the middle third of face 2.

The punishment ERR given in case some of these requirements are not met is indicated on Figure 3.9.1.

The numerical value of "score" is then calculated as :

$$SCORE = SUM(ERR) / N \qquad (3.9.1)$$

where the sum is taken over the N slices.

Solution Score for Some Special Cases

Some of the solution methods used by BEAST (see Appendix E) are incomplete, i.e. some of the slice forces and/or moment arms shown on Figure 3.6.1 are not known. For such cases the score value is set to one of the values listed below.

6.666	Force equilibrium solution, moments are neglected
7.777	Shear surface intersects a rigid material, no analysis
8.888	Bishop's simplified method, horizontal forces not known
9.999	Circular shear surface in clays, moment equilibrium only, only S-forces known

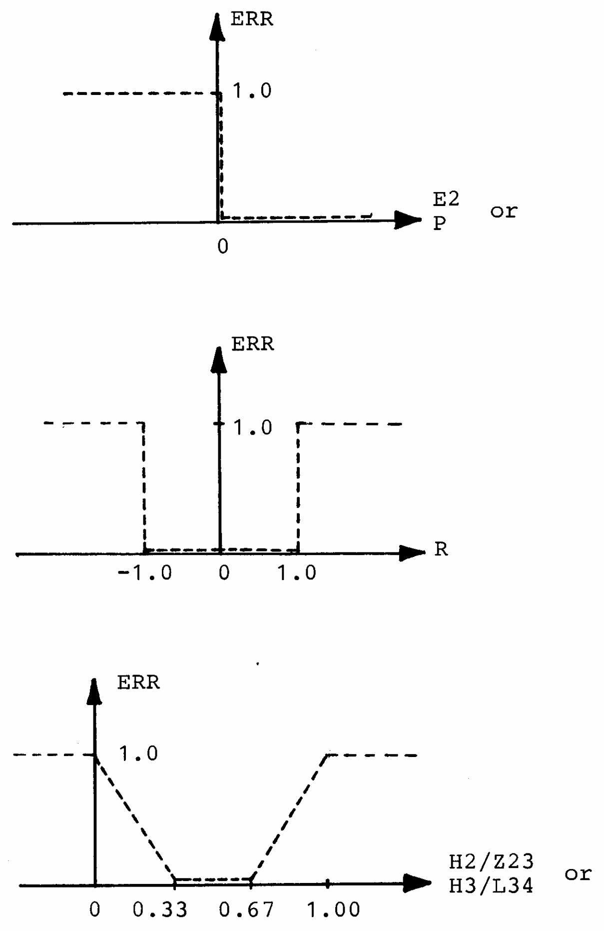


Figure 3.9.1 : Procedures Used to Find Solution Score

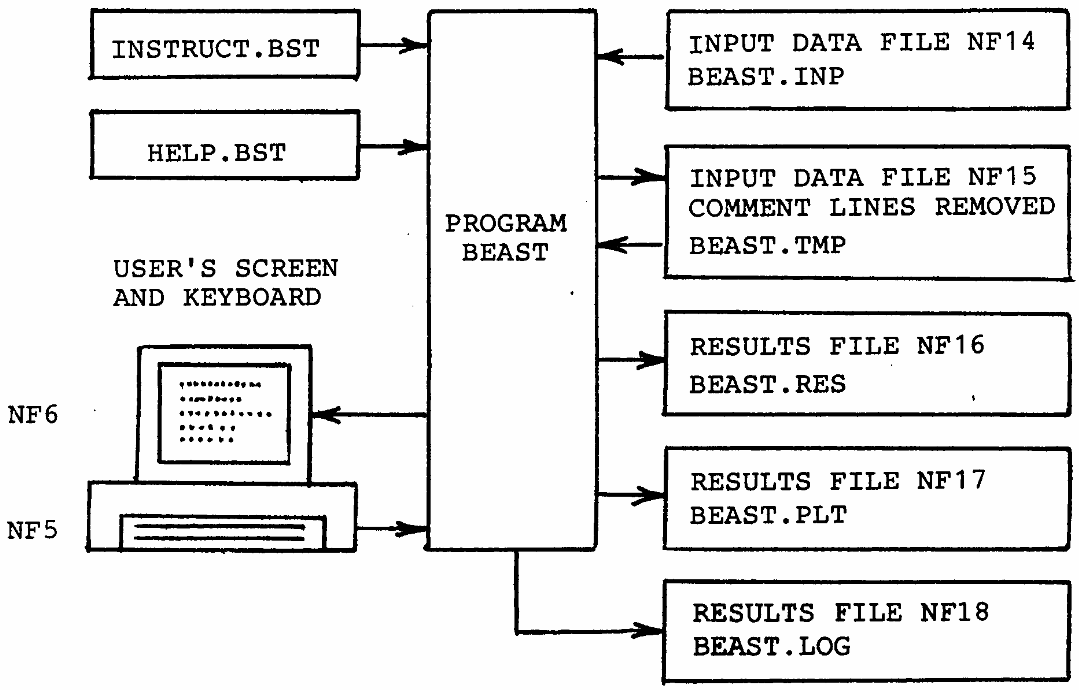
4.0 USER'S GUIDE

4.1 General System Description

Program BEAST operates interactively, i.e. questions, different options and messages are displayed at the user's screen, and the user must give the instructions needed from his keyboard. In order to limit the user/machine communication, a formatted input file, NF14, that contains most of the data needed is read by BEAST at the start of the run.

File NF14 may contain comment lines for detailed explanation of the parameters used. BEAST generates a new input file NF15 with such lines removed. Section 4.2 presents a detailed description of file content.

The figure below shows the different parts of the system. The file names indicated are the names that BEAST either expects to find in the present directory, or the names that BEAST will give to the result files.



The files NF5 and NF6 may be replaced by the files INP and RES, see IPRTTP in Section 4.2

Figure 4.1.1 : BEAST General System.

4.2 Input Data File NF14

The next pages show an example input file to BEAST for the below combined slope stability and bearing capacity problem.

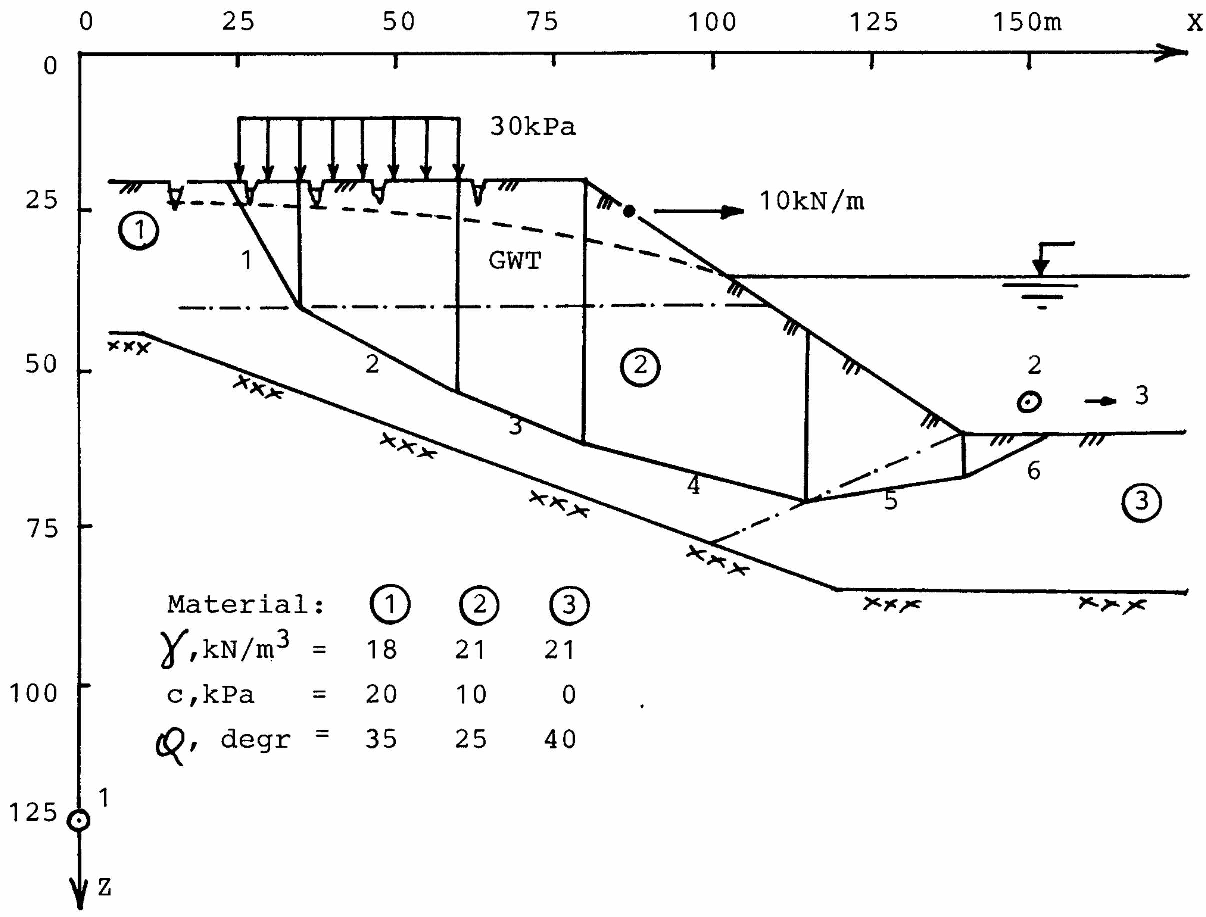


Figure 4.2.1 : Input File NF14 Demonstration Example

The remaining pages of this section present the NF14 input file for the above example, followed by a detailed explanation of the different values BEAST may read from input file NF15, which is identical to file NF14 except for the comment lines, see below.

Notice that the line numbers included in the example input file are there for reference purpose only. They should not be part of an actual BEAST input file.

```
BEAST  PROGRAM DOCUMENTATION REPORT  SECTION 4.2  TEST EXAMPLE
SLOPE WITH SURFACE LOADING    11 Apr 2003
*
* Date         Sign   Log of file modifications
* -----------  ----   ----------------------------------------------------
* 13 Oct 1993  cjfc   Original version, units used are : kN & m
* 11 Apr 2003  cjfc   Include extra input line with MISC1-5 and VAL1-5
*

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1      IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   01      IDEFTO    ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
    1      NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
    0      NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0      SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.00 0.00           VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.00 1.00 0.00      VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0      ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    1      ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0      JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -1      IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    2      JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000    CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  2.000    CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
C                     = 0.000 : FIND ZERO SCORE SOLUTION WITH HIGHEST SF
C                     = 0.001 TO 0.999 : TAKE FIRST SOLUTION WITH LOWER SCORE
C                     = 1.000+ : USE INTERSLICE ROUGHNESS FACTOR 1.0
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
    6      NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    4      NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    2      NUMLAY    NUMBER OF HORIZONTAL LAYERS
    1      NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
     0        20        44     1
    10        20        44     7
    80        20        70     4
   120        47        85     2
   140        60        85     4
   180        60        85     0
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
    1       40      1
    2      100      2
  TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
    1          3        0  121     150  55    1.0E6 55
 0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

 ****************** MATERIAL PROPERTIES SECTION
    3      NUMMAT    NUMBER OF DIFFERENT MATERIALS
    0      NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
    0      NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
  5.0      CRACKZ    SURFACE OPEN CRACK DEPTH
  2.0      CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
  0.0      PHIREF    FRICTION ANGLE REFERENCE PRESSURE
 EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
  1     18      20     35      0       0       0       0      0     0      0
  2     21      10     25      0       0       0       0      0     0      0
  3     21       0     40      0       0       0       0      0     0      0
 TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
  1     18      1.00    1.00    1.00      0
  2     21      1.00    1.00    1.00      0
  3     21      1.00    1.00    1.00      0
 X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
 NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)
```

```

 ****************** PORE-WATER-PRESSURES SECTION
    2      IDPWP      PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
    5      NUMXPW     NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
    0      NODPWP     NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
    0      FCTNOD     FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
   0.0     WATERZ     HORIZONTAL WATER TABLE Z-LEVEL
  10.0     GAMWAT     FREE WATER UNIT WEIGHT
   0.0     GAMPWP     PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
   0.0     PWPMIN     MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
    1        10       2        24     44
                                0    190
    2        50       2        25     57
                                0    310
    3        75       2        29     65
                                0    380
    4       103       2        35     73
                                0    450
    5       140       3        35     60  85
                                0    250  550
  NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)

 ****************** LOAD SECTION
    0      NUMPNT               NUMBER OF POINT (I.E. LINE) LOADS
    1      NUMSIG               NUMBER OF SURFACE DISTRIBUTED LOADS
   0.0     SIGTOP               UNIFORM INITIAL VERTICAL STRESS AT SURFACE
  0.0 0.0 XTOP1,XTOP2           STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
  1.0 1.0 FCTPNT,FCTSIG         POINT AND DISTRIBUTED LOAD FACTORS
  0.0 1.0 ACCXRT,ACCZRT         ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
  POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
  STRIP     X1        X2       SIGZ1     SIGZ2     TAUX1     TAUX2
    1       25        60         30        30        0         0

 **************** GIVEN SHEAR SURFACE
   1   7              SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
  24    34    60    80   115   140   152   X-COORDS
  20    40    53    61    70    66    60   Z-COORDS
   0     0     0     0     0     0         PWP-VALUES SLICE CENTER

End of BEAST input file c:\cjfc\beast\test\data\testx00.002
```

General

The user prepares input file NF14 by means of a text editor and an old input file. The NF14 file must be located in the BEAST directory and named BEAST.INP

BEAST reads each line of file NF14 and checks the character in column 1. If this character is neither a 'C' nor a '*', the line is copied to file NF15. If the character is a 'C' or a '*', that line is not included on file NF15. This allows the user to include comment lines with detailed explanations at any position of the input file.

The data on file NF15 is then read format free, i.e. the values may be placed anywhere on the line, or on several lines, as long as all required values are given. Note that zeros must be included. Integer values must be given without a decimal point, real values can be given with or without a decimal point. Two numbers are separated by at least one blank.

Blank lines and heading lines are there to make file inspection as easy as possible. These lines must be included even if BEAST does not use the text on the lines for any purpose.

Table heading lines for data that is not included are required to be present, see for example the last two lines of the pore water pressures section for the above example.

Label Lines

The two first lines of the data file are text lines read for identification purposes. The first 80 columns on each line are printed to the user's screen and to output files NF16, NF17and NF18.

****** Control Section

CONFRC , CONLTH

Conversion factors w.r.t. force and length. All input values are multiplied by these factors, as appropriate, in order to obtain new output units. Note that values given by the user during the interactive communication with BEAST are not multiplied with these factors.

FCTSUC , FCTTAN

Soil strength material factors w.r.t. given undrained shear strength and/or cohesion, and tan(PHI) where PHI is the angle of internal friction. Note that the values are factors :

SU.USED = SU.GIVEN * FCTSUC

TAN(PHI).USED = TAN(PHI).GIVEN * FCTTAN

IDTYP

The user must specify the type of problem to be analysed :

IDTYP = 1 Stability or bearing capacity problem
IDTYP = 2 Earth pressure problem

IDEFTO

The input value of this parameter is used by BEAST to decide upon (1) which of the five solution methods to be used, and (2) the analysis type to be used, i.e. effective stress, total stress or combined analysis. IDEFTO may have any of the 15 (5 methods x 3 types) allowed input values listed in Appendix E, Table E1.1, which is included below. As an example, an effective stress analysis by the Bishop modified method requires an IDEFTO input value of 21. The parameter METHOD is then set to 2, and the revised IDEFTO value is set to 1.

The parameter IDEFTO read from file NF14 may have one of the 15 values listed.
It is used to set the value of METHOD and the revised value for IDEFTO.

Solution method parameter METHOD	Solution type parameter IDEFTO		
	1	2	3
	Eff. stress	Tot. stress	Combined
-1 Force equilibrium	-1	-2	-3
0 BEAST 1988-2002	1	2	3
1 Bishop Simplified	11	12	13
2 Bishop modified	21	22	23
3 BEAST 2003	31	32	33

NUMGEN

Number of general shear surfaces to be read from the input file. See the below General Shear Surfaces Section for details. BEAST may either analyse such general shear surfaces, or other special surfaces specified by the user during program operation. Maximum allowed NUMGEN value is 30.

NUMSLC

Number of slices of equal width that the shear surface shall be divided into. NUMSLC = 0 is allowed for general surfaces (see NUMGEN above). In that case BEAST will use a slice division corresponding to the points given on the general surface. Maximum allowed value = 99.

SIDSHR

Side shear factor. BEAST assumes plane strain conditions, i.e. the system analysed is infinitely long in the Y-direction. In case the user wants to include shear forces on the two end or side surfaces, a positive value of SIDSHR will do that. For example, the system analysed is 50 m long in the Y-direction and full side shear at both end surfaces shall be included. The side shear factor should then be :

SIDSHR = 2.0 / 50.0 = 0.04 (4.2.1)

Procedures used to find the side shear force are explained in Section 3.5. This force is multiplied by SIDSHR.

H3-VALUES

The two values (H31 and H32) are used to describe the location of the effective normal force P against the slice bottom, see Figure 3.6.1. H31 is the H3/D34 value at the start of the shear surface, H32 the value at the end, where D34 is the slice bottom length. A linear variation of H3/D34 is assumed in between.

Both H31 and H32 equal to zero is interpreted by BEAST to mean that the normal force P shall act through a point directly below the combined centre of gravity for slice self weight and external vertical loading.

R-VALUES

The three values R1, R2 and R3 are used to describe the variation of interslice shear mobilisation (roughness) along the system of slices. Zero means no shear stresses between slices, +1.0 or -1.0 means that the Mohr-Coulomb strength is fully mobilised.

The initial roughness value Ro at any vertical section is computed from :

Ro = R1 + (R2-R1)*X/XTOT + R3*H(X)/HMAX (4.2.2)

where

X =	Distance from the start of shear surface to the vertical section considered.
XTOT =	Total horizontal length from start to end of the shear surface.
H(X) =	Height of vertical section.
HMAX =	Maximum height of any vertical section.

ITENSP

Used in score calculation only. If non-zero, a negative P force will not increase the calculated score value.

ITENSE

Used in score calculation only. If non-zero, a negative E2 force will not increase the calculated score value.

JPRINT

This code governs the volume of trace print to the file BEAST.LOG. Values from 0 to 3 may be specified, the higher the value, the more detailed the trace print. Values higher than 1 may generate considerable output volumes and are only intended for program checking purposes.

IPRTTP

Print type indicator. The user may choose if the detailed shear surface results printed to file NF16 shall contain slice forces or slice stresses.

IPRTTP = 1 Print slice forces
IPRTTP = 2 Print slice stresses

The user may want to analyse a given data set several times, for example to see the effects of parameter changes, or for program checking purposes. A negative value of IPRTTP (-1 or -2) will cause the data normally supplied by the user via the keyboard to be read from the file INP. Results normally displayed at the user's screen will be printed to the file RES. This switch will only be activated if the label IPRTTP is placed in positions 11-16 of the line read.

JPLOT

BEAST may generate line printer type plots on output file NF16. The following options exist :

JPLOT = 0 No plots wanted.
JPLOT = 1 Make a sketch of shear surface with material id's and calculated stresses.
JPLOT = 2 Also include a sketch of Su0 or PWP at the mesh nodal points.
JPLOT = 3 Also include a listing of mesh nodal points and elements.

CRTFRC

Convergence criterion for forces. Used to decide when the unbalanced E2 force computed at the last slice is so small that the iterations can be stopped. If zero is specified, BEAST will set CRTFRC to the sum of all vertical slice forces divided by 10,000.

CRTSCR

Convergence criterion for solution score. This parameter is only used with the BEAST 1988-2002 method, see Appendix E.

CRTSCR = 0.0 Find the lowest score solution. If several solutions with zero score exist, take the one with the highest safety factor.

CRTSCR = 0.001 - 0.999 Take first solution with lower score than CRTSCR.

CRTSCR > 1.0 Use the given Ro values and accept the solution independent of score value.

MISC1, MISC2, MISC3, MISC4, MISC5, VAL1, ... , VAL5

Special purpose parameters for future use. Only MISC1 is presently used. MISC1 = 1 flags that BEAST is allowed to modify a too steep shear surface exit angle. The criterion used is that an exit angle steeper than 45° - φ'/2 is replaced by that value.

****** Geometry Section

NUMXLN

Number of X-lines that are required to form the mesh that covers the area to be analysed. Minimum allowed value is 0, maximum value is 101. See Figure 3.3.2 for an example mesh. If zero is specified, BEAST generates two X-lines at X = -1000 and X = +1000 with the horizontal soil surface at Z = 0.0.

NUMELZ

Number of elements in the Z direction at equal spacing in the mesh. Minimum allowed value is 0, maximum allowed value is 35.

NUMLAY

Number of horizontal layers. Zero is allowed, maximum allowed value is 35. Layer depths and material identifications are read below.

NUMTRI

Number of triangles that shall be read with given material identifications. Triangles may partly cover each other, the one with the lowest number gets priority. See Section 3.3 for detailed procedures used to assign material id. to a point. Maximum allowed value is 150.

For the example on Figure 4.2.1 a material triangle is used to model the presence of material 3. The locations of the triangle corner points 1, 2 and 3 are indicated on the figure.

X-LINE TABLE WITH SOIL AND ROCK SURFACE

Number of vertical X-lines in this table was given as NUMXLN above. Lines must be in increasing X order. Z-surface must be located above (lower Z value) Z-rock. More than one column of elements may be placed between present X line and next X line. Let the sum of number of X elements to next line in this table be called NSX. We then have :

Number of Mesh Elements = NSX * NUMELZ (4.2.3)

Number of Mesh Nodes = (NSX+1) * (NUMELZ+1) (4.2.4)

NODAL POINT NEW Z-VALUES

Lines of this type are read until NP1 = 0 or NP2 = Number of mesh nodal points. The lines may be used to modify the Z-values generated for some or all nodal points.

NP1 = First nodal point to be included
NP2 = Last nodal point to be included
NSTEP = Step value from NP1 to NP2
ZN1 = New Z value at node NP1
ZN2 = New Z value at node NP2

BEAST checks that the shifted node position is above the first node below the present node. If NP1 = 0, no nodal point shift operations are carried out, and no more lines are read.

ELEMENT MATERIAL MODIFICATIONS

Lines of this type are read until NE1 = 0 or NE2 = Number of mesh elements. The lines may be used to modify the element soil material identification numbers. BEAST sets all material identification numbers to 1 before modification lines are read.

NE1 = First element to be included
NE2 = Last element to be included
NSTEP = Step value from NE1 to NE2
MAT = New material identification number

If NE1 = 0, no modifications are carried out, and no more lines are read.

HORIZONTAL LAYER TABLE

Number of lines in this table was given as NUMLAY above. The Z-values at the bottom of the layers must be in increasing order.

MATERIAL TRIANGLES TABLE

Number of lines in this table was given as NUMTRI above. If more than one triangle, and the triangles overlap, give the "top" triangle first. A point gets the material identification of the first triangle found, inside which the point is located.

The 3 corner points (X1,Z1), (X2,Z2) and (X3,Z3) may be in any sequence.

WALL DATA

The three values XWALL, HWALL and RWALL are read even if the problem to be analysed is one of stability or bearing capacity.

XWALL = X co-ordinate of the vertical wall.
HWALL = Wall height, i.e. distance from soil surface to the bottom of the wall.
RWALL = Roughness R at the wall.

The interslice roughness R is taken to vary linearly from R1 at the start of the shear surface to RWALL at the wall itself. Positive R values mean that the soil "hangs" on the wall in the active case, and "lifts" the wall in the passive case.

****** Material Properties Section

NUMMAT

Number of different materials. The value given must at least be equal to the maximum material identification read as part of the above Geometry Section. Maximum allowed value is 50.

NUMXSU

Number of vertical X-lines with given Su0 variation with depth, see below. Maximum allowed value is 25.

NODSU

Number of nodal points where undrained shear strength values are given. Maximum allowed value equals number of nodal points in the mesh generated.

CRACKZ

Depth below soil surface of an open crack in the active zone. See Figure 3.5.1 for an explanation of procedure used to generate modified geometry.

CRACKW

Depth of water in the crack, i.e. distance from the water surface to the crack bottom. Water unit weight used to find the corresponding force is taken from the below PWP section.

PHIREF

Friction angle reference pressure. Used to model a friction angle that depends upon the effective normal stress, see PHIANG below. Zero is only allowed if PHIRED is zero for all materials.

EFFECTIVE STRESS MATERIAL PROPERTIES

One line is read for each material, even if total stress analysis was specified.

GAMTOT

Total unit weight.

COHSN

Cohesion to be used in an effective stress analysis. In case the "attraction" is known, rather than the cohesion, we have :

Cohesion = Attraction * tan(PHI) (4.2.5)

PHIANG

Effective angle of internal friction in degrees. The PHI value may be specified to depend upon the effective normal stress SIG :

PHI = PHIANG - PHIRED * Log10(SIG/PHIREF) (4.2.6)

PHIRED

Used to model stress dependent friction angles, see above.

PWPMAT

In case of non-hydrostatic PWP BEAST allows several different options by which the resulting PWP can be calculated. One option is simply to assign a PWPMAT value to each material.

RU-MAT

For certain groups of problems PWPs may be expressed as a ratio of the total overburden stress, for example in connection with earth embankments. At a point (X,Z) we thus have :

PWP = GAMMA*H*RU + PWPMAT + ... (4.2.7)

PWP = Pore water pressure
GAMMA = Average total unit weight
H = Vertical distance from the point to the soil surface
RU = Given constant for each material type

Note that the resulting PWP is found as a sum of several contributions. A negative RU may be used to flag that the resulting PWP shall only include the RU contribution, see Section 3.4.

B-FACT

Undrained effective stress analysis (UESA) PWP parameter. A B-FACT greater than zero is used to flag that an UESA type solution is wanted. The change in pore water pressure is calculated as :

DELPWP = BFACT * (DELSIGAVR - D * DELSIGDEV) (4.2.8)

The two values K-NOT and B-SIG2 described below are only needed if UESA is wanted. The value D-FCT may be used to specify the limiting matrix suction for individual materials, see below.

K-NOT

Initial horizontal effective stress divided by initial vertical effective stress.

B-SIG2

Value used to compute the intermediate principal effective stress SIG2 :

SIG2 = SIG3 + B * (SIG1 - SIG3) (4.2.9)

D-FCT

Factor on the D-parameter in the above DELPWP equation. The D-parameter values are calculated from the Su(BETA) values, see below :

D = DFCT * Su(BETA) (4.2.10)

For a normal (i.e. non UESA) type analysis the value of D-FCT may be used to establish a maximum allowed matrix suction valid for each different material :

Maximum suction = Minimum allowed PWP = PWPMIN * D-FCT (4.2.11)

where the value PWPMIN was read at line 83 of the example input file. In case D-FCT is given as exactly zero, u.min is taken as PWPMIN.

TOTAL STRESS MATERIAL PROPERTIES

One line is read for each material, even if effective stress analysis was specified.

GAMTOT

Total unit weight.

SUA/SU0

Anisotropic shear strength ratio for active triaxial tests, corresponding to a shear plane inclination of +45 degrees, see Figure 3.3.1.

SUD/SU0

Anisotropic shear strength ratio for direct simple shear tests, corresponding to a shear plane inclination of 0 degrees.

SUP/SU0

Anisotropic shear strength ratio for passive triaxial tests, corresponding to a shear plane inclination of -45 degrees.

SU0-MAT

Value of Su0 for each material. Will be added to X-line and node Su0 values given below.

SU0 GIVEN BY VERTICAL X-LINES

Number of X-lines to be given was specified as NUMXSU above. X-COORD is the X co-ordinate value for each line. Z-POINTS is number of points with depth on the present X-line. Then follows the Z values for each point 1 to Z-POINTS, and on next line, the corresponding Su0 values.

Interpolation between the X-lines is carried out as shown on Figure 3.4.1 for pore water pressures.

SU0 GIVEN BY NODES

Number of nodes for which Su0 values shall be read was specified as NODSU above. If NODSU equals number of nodes in the mesh, the node numbers shall not be included. Figure 3.3.2 shows the procedure used to determine Su0 value at point (X,Z) by interpolation between mesh nodal points.

ALTERNATIVE INTERPRETATION OF SU0 VALUES

In case of effective stress analysis, and an UESA type solution, the given Su0 values will be interpreted as D-parameters to be used to calculate pore water pressure changes. See Appendix B for further details.

In case of effective stress analysis, and a material has been given both COHSN and PHIANG as zero, COHSN will be replaced by the calculated Su value.

****** Pore-Water-Pressures Section

IDPWP

The user specifies if hydrostatic or non-hydrostatic PWP exists. This allows BEAST to save some time in connection with hydrostatic PWP.

IDPWP = 1 Hydrostatic
IDPWP = 2 Non-hydrostatic

A number of different options exist w.r.t. how PWP values can be specified, see Figure 3.4.1. Note that in the case of non-hydrostatic PWP the individual contributions are added together, with the exceptions listed in Section 3.4.

NUMXPW

Number of vertical profiles (X-lines) where PWP values at different Z-levels are given. Maximum allowed value is 25.

NODPWP

Number of nodal points for which a PWP value has been given. Maximum value allowed is number of mesh nodal points.

FCTNOD

Factor that PWP values given at the nodal points will be multiplied with. Allows scaling without changing the actual PWP values given.

WATERZ

Z-level for the horizontal water table. The water table is assumed to extend over the entire length of the system, i.e. an earth dam will get the same water level upstream and downstream. If this is not wanted, use the NUMXPW option instead.

GAMWAT

Unit weight of free water above the soil surface, and/or water in cracks.

GAMPWP

Pore water fluid unit weight. See equations (3.4.3) and (3.4.4) for how PWP values are computed, depending upon if the soil surface is submerged or not.

PWPMIN

Minimum allowed PWP value. Points located above the free water surface, or above the ground water table, may get negative PWP values. If the resulting PWP value becomes smaller than PWPMIN, PWPMIN is used. PWPMIN may be negative as a result of capillary tension.

The PWPMIN value read as input is multiplied by the D-FCT value as described above, in order to enable the modelling of a material dependent minimum allowed PWP value (i.e. a maximum allowed matrix suction).

PWP GIVEN BY VERTICAL X-LINES

Number of X-lines to be included was given as NUMXPW above. X-COORD is the X co-ordinate value for each line. Z-POINTS is number of points with depth on the present X-line. Then follows the Z values for each point 1 to Z-POINTS, and on next line, the corresponding PWP values.

Interpolation between the X-lines is carried out along a line parallel to the ground water table, see Figure 3.4.1.

PWP GIVEN BY NODES

Number of nodes for which PWP values shall be read was specified as NODPWP above. If NODPWP equals number of nodes in the mesh, the node numbers shall not be included. Figure 3.3.2 shows the procedure used to determine PWP value at point (X,Z) by interpolation between mesh nodal points.

**** Load Section

NUMPNT

Number of point (line) loads to be read from the table starting on line 95. This value is also used to flag the presence of piles and/or soil nails as explained below.

NUMSIG

Number of sections with given surface distributed stresses in the vertical and the horizontal direction. Maximum allowed number is 20.

SIGTOP

Initial vertical stress acting against the soil surface. May be needed for UESA initial stress calculations.

XTOP1 , XTOP2

Stress SIGTOP (see above) acts from X = XTOP1 to X = XTOP2.

FCTPNT , FCTSIG

Load factors that the below point forces and distributed stresses are multiplied by.

ACCXRT , ACCZRT

Acceleration ratios in the horizontal and in the vertical directions. The values are applied to the slice self weights only, and not for example computed external water pressures. For normal cases without dynamic effects ACCXRT = 0.0 and ACCZRT = 1.0 would be used.

POINT FORCE DATA TABLE

Number of lines in this table is given by NUMPNT above. Point forces may be located anywhere inside or outside the soil volume. For a given shear surface only forces located above the surface will be included. The forces will, together with the corresponding moment, be placed at the slice centres.

SURFACE STRESS DATA TABLE

Number of lines in this table is given by NUMSIG above. BEAST assumes that the given distributed stresses act at the soil surface.

STRIP =	1,2,3,...,NUMSIG
X1 =	X co-ordinate at start of loaded section
X2 =	X co-ordinate at end of loaded section
SIGZ1 =	Vertical stress at X1
SIGZ2 =	Vertical stress at X2
TAUX1 =	Horizontal shear stress at X1
TAUX2 =	Horizontal shear stress at X2

SIG and TAU have units force/length**2 and act on the horizontal projection of the soil surface. Sections with distributed loading are allowed to overlap. X2 must be higher than X1.

SOIL NAILS

The presence of piles and/or soil nails in the system is flagged by a value of NUMPNT (number of point loads, see above) that is higher than 100. In that case, the value of NUMPNT is broken into two digits :

NAILS = NUMPNT / 100
NUMPNT = NUMPNT - 100 * NAILS

As an example, NUMPNT = 1802 would be replaced by NAILS = 18 and NUMPNT = 2.

In case NAILS is non-zero, the pile/soil nail data will be read from a table placed at the end of the Load Section, as described in Appendix D. A case that includes soil nails is included as example no. 12 in Appendix C.

****** General Shear Surface Section

SURFACE NUMBER , NUMBER OF POINTS

Each general shear surface has an identification number 1,2,3,... up to NUMGEN given in the Control Section. Maximum allowed value of NUMGEN is 30.

Each general shear surface may have up to 100 points with given X- and Z co-ordinates.

X CO-ORDINATES

General shear surface X co-ordinates, number of values to be read was given above. X co-ordinates must be in increasing order.

Z CO-ORDINATES

General shear surface Z co-ordinates corresponding to the above X values.

PWP VALUES

In case non-hydrostatic PWP was specified (IDPWP=2), BEAST expects to find a line with PWP values after the two co-ordinate lines for each shear surface.

The interpretation of these values depends upon the number of slices specified above, NUMSLC :

NP = Number of points (X,Z) given on the shear surface.

NUMSLC = 0 Slice division corresponding to the given points on the shear surface shall be used. PWP values are assumed given for the mid point at the bottom of each slice, i.e. NP-1 values are read.

NUMSLC = N Each general shear surface shall be divided into N slices of equal width. PWP values are assumed given at each (X,Z) point specified on the shear surface, i.e. NP values are read.

INITIAL STRESS VALUES

In case UESA was specified (non-zero B factor), BEAST will ask the user if initial stress values shall be read for general shear surfaces. If yes, the PWP values line must be followed by one line with initial effective normal stresses, and another line with initial shear stresses.

The interpretation of where these initial stresses act will depend upon the value of NUMSLC as explained for PWP above.

4.3 Interaction Between Program and User

The first part of this section describes the different requests that BEAST may present to the user. A typical program/user interaction sequence for the Figure 4.2.1 demonstration example is shown at the end of this section.

Initial Requests

DO YOU NEED INSTRUCTIONS (Y/N) ......

The user may obtain information related to the following subjects :

1. Getting Started
2. Input/Output Files
3. Preparation of Input File
4. Running the Program
5. User Notebook

Each section contains a summary of the information included in the program manual. Option 3, however, gives the complete description of the input data file NF14 to be prepared by the user. This data is stored on an independent text file INSTRUCT.BST that may by modified and updated as wanted by means of a text editor.

SHALL ECHO PRINT OF INPUT DATA BE MADE (Y/N) .....

If yes, the content of input data file NF14 with comment lines is printed at the start of output file NF16.

BEAST then reads the input data file NF14, generates file NF15 and reads the values needed from this last file. A detailed description of file content is given in Section 4.2. Further actions by BEAST will be after interactive communication with the user.

BEAST displays a number of requests that are explained below. The user provides answers that may be numbers on a menu, yes or no, co-ordinate values, etc. If the user makes an error in the input list, intentional or unintentional, BEAST will in most cases give program control to the Central Decision Point (CDP). In case the answer provided by the user is found not acceptable, the input data request is either repeated or the control given to CDP.

Central Decision Point

After BEAST has read the input file, a short summary of this data is displayed at the user's screen, and the program control reach CDP. After an instruction has been carried out, for example analysis of a group of shear surfaces, control is returned to CDP.

At CDP the program displays the following menu :

```
----- PROGRAM CONTROL IS AT CENTRAL DECISION POINT
----- SPECIFY NEXT OPERATION PLEASE
-----  1  :  TRY A NEW SHEAR SURFACE
-----  2  :  PRINT LAST SURFACE DATA TO FILE NF16
-----  3  :  SAVE LAST SURFACE FOR POST PROCESSOR
-----  4  :  PRINT BEST SURFACE DATA TO FILE NF16
-----  5  :  SAVE BEST SURFACE FOR POST PROCESSOR
-----  6  :  READ CONTROL DATA MODIFICATIONS
-----  7  :  HELP !
-----  8  :  TERMINATE
```

Reply 1 will cause a range of possible requests that are described in the last part of this section.

Replies 2,3,4 and 5 will not require further input from the user.

Reply 6 will cause a request for modified control data, see below.

Reply 7 will display the HELP menu, see below.

CDP Reply = 6   Read Control Data Modifications

The user may want to modify the control data read from file NF15 in the middle of an analysis sequence. This can of course always be achieved by termination of the present run, modification of the input file and start of a new BEAST run. However, it will be easier and faster for the user to carry out such modifications as a part of the interactive operations.

When modifications are requested, BEAST will display a line with the present values of the following control parameters :

CRTSCR	Score criterion
R1,R2,R3	Values used to determine initial Ro values
H31,H32	Position of P force against slice bottom
JPRINT	Trace print code
JPLOT	Code for plots on print file NF16
NUMSLC	Number of slices to be used

Section 4.2 contains a detailed description of the above parameters.

The user specifies new values to replace the old ones. Note that many computers allow an incomplete input list to be terminated by a slash (/). As an example, an input line like :

```
2.0   0.45   0.55  /
```

would cause CRTSCR, R1 and R2 to get the above new values, while the remaining parameters keep the value they had before execution of the read statement.

CDP Reply = 7 Activate HELP Facility

The HELP facility has been included to allow the user to solve problems that may occur during program operation, or to interpret error messages, without having a BEAST manual available.

When activated the following menu is displayed :

1. Input Data Error Codes
2. Available Shear Surfaces
3. Control Data Explanation
4. Print / Save / Last / Best
5. Execution Error Messages
6. User Notebook

The HELP facility first reads the wanted sections 1 to 6 of text file HELP.BST. The user may then display this section on his screen page by page. The HELP.BST file may be modified by means of a text editor. Section 6, User Notebook, is provided for the user to make notes about problems or errors that have previously occurred, and how they were overcome.

CDP REPLY = 1 Try a New Shear Surface

BEAST's next display will be a request for the type of surface to be analysed :

1 = General shear surface
2 = Circular shear surface(s)
3 = Combined shear surface(s)
4 = Plane shear surface(s) in the case of earth pressure calculation.

Data that will be requested by BEAST for each of these surface types are explained on the following pages.

General Shear Surface

The user has selected 1 on the shear surface type menu. The next request will be :

GIVE GENERAL SURFACE NUMBER AND MODIFICATION INSTRUCTIONS
NUM X-SHIFT Z-SHIFT X-MULT Z-MULT

NUM = General shear surface number, referring to the shear surface(s) included at the end of input file NF14.

X-SHIFT = Z-SHIFT The surface selected is shifted in the X and Z direction by these amounts.

X-MULT = Z-MULT The surface selected is "stretched" in the horizontal and in the vertical direction by these amounts. The starting point of the surface is not moved (unless the above shift values are non-zero).

Stretching in the Z-direction will be with respect to the straight line that connects the first and the last given point on the general shear surface.

It should be noted that the use of the shift and the stretching options will invalidate the PWP and the initial stress values given for general shear surfaces if these values are non-zero.

BEAST solves the general shear surface and displays the safety factor and the solution score found. Program then asks :

SHALL NEW GENERAL SURFACE BE TRIED (Y/N) .....

Acceptable answers are Y (yes) or N (no), that may be preceded by any number of blanks, and followed by any characters. If Yes, data for a new general surface is requested. If No, program control is returned to CDP.

Circular Shear Surface

The user has selected 2 on the shear surface type menu. The next request will be :

GIVE CIRCLE SEARCH CODE : 1-SINGLE 2-STEP 3-FULL ....

In case SINGLE is specified, BEAST will request the location of the circular shear surface to be analysed :

X-CNTR Z-CNTR RADIUS X-FIX Z-FIX , PLEASE SPECIFY

The user must give the co-ordinates for the circle centre. If RADIUS is given as zero, BEAST will let the surface pass through point (X-FIX,Z-FIX).

In case STEP is specified, BEAST will request data for a stepwise search from an assumed critical circle centre :

GIVE : XFIX,ZFIX = FIXED POINT THAT ALL CIRCLES SHALL PASS
ZLVFIX = Z-LEVEL THAT ALL CIRCLES SHALL TOUCH
XC,ZC = CIRCLE CENTER LOCATION GUESS
DXZ = STEP VALUE FOR CIRCLE CENTER SHIFT
XFIX ZFIX ZLVFIX XC ZC DXZ

Either (XFIX,ZFIX) or ZLVFIX must be specified as non-zero.

In this mode BEAST will search within a square grid of side length 8 times DXZ with (XC,ZC) at its centre. The grid consists of 9 by 9 = 81 points. The search starts at the assumed centre, and is continued until a grid point is found with a safety factor that is lower than the safety factor at all the neighbour grid points.

It should be noted that for cases with large soil strength variation, or special loading, the first minimum safety factor found by the above approach need not be the very lowest one.

In case FULL is specified, BEAST will request data for a complete search with the circle centre located inside a given rectangle :

GIVE : XFIX,ZFIX = FIX POINT COORDS, ALL CIRCLES PASS THROUGH
ZLVFIX = FIXED Z-LEVEL, ALL CIRCLES TOUCH
XCMIN,XCMAX = CIRCLE CENTER X-BOUNDARIES
ZCMIN,ZCMAX = CIRCLE CENTER Z-BOUNDARIES
NX,NZ = NUMBER OF DIVISIONS IN X- AND Z-DIRECTIONS
XFIX ZFIX ZLVFIX XCMIN XCMAX ZCMIN ZCMAX NX NZ

Either (XFIX,ZFIX) or ZLVFIX must be specified as non-zero. Number of circles to be tried will be (NX+1)*(NZ+1).

For both search modes (STEP and FULL) a trace print of circle location, safety factor and solution score will be displayed at the user's screen.

When finished, BEAST will request if a new search or a new single circle shall be tried. If not, control is returned to CDP.

Combined Shear Surfaces

The user has selected 3 on the shear surface type menu. The next request will be :

GIVE TYPE OF COMBINED SURFACE TO BE USED
1 : CIRCLE CENTER ABOVE SHEAR SURFACE
2 : CIRCLE CENTER BELOW SHEAR SURFACE
3 : TYPE 2 , REPLACED BY CANTILEVERED BEAM SHAPE

Figure 4.3.1 shows a sketch of these 3 different types of combined shear surfaces that may be analysed by BEAST, and also used for automatic searches.

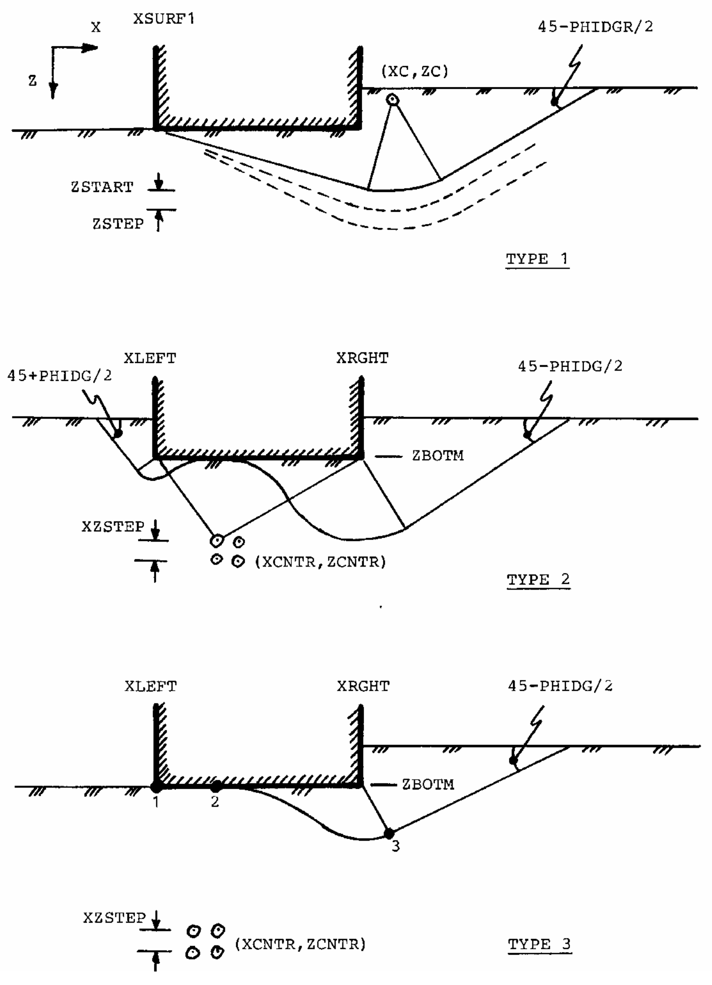


Figure 4.3.1 : Combined Shear Surface Types

Combined Surface Type 1 consists of a straight line, a circle with its centre above the shear surface, and another straight line. Different shear surfaces are generated by increasing the radius of the circle. The user is requested to give the following values (see Figure 4.3.1) :

GIVE : XSURF1 = LEFT INTERSCTN BETWEEN SHEAR PLANE AND SOIL SURF.
XC,ZC = CIRCLE CENTER CO-ORDINATES
ZSTART = START SHEAR SURFACE Z-LEVEL
ZSTEP = SHEAR SURFACE Z-DIRECTION STEP VALUE
NZ = NUMBER OF SHEAR SURFACES TO BE TRIED
PHIDGR = PHI-ANGLE FOR EXIT SLOPE (= 45 - PHIDGR/2)
XSURF1 XC ZC ZSTART ZSTEP NZ PHIDGR

Combined Surface Type 2 consists of 3 circular arch sections and 2 straight lines at the start and the end of the shear surface. Different shear surfaces are generated by shifting the middle circle centre, located below the shear surface, in the X and the Z direction. The user is requested to give the following values (see Figure 4.3.1) :

GIVE : XLEFT = BASE LEFT CORNER X-VALUE
XRGHT = BASE RIGHT CORNER X-VALUE
ZBOTM = BASE BOTTOM Z-VALUE, CIRCLES TOUCH BASE
XCNTR = CIRCLE CENTER X-COORD GUESS
ZCNTR = CIRCLE CENTER Z-COORD GUESS
XZSTP = STEP VALUE FOR CIRCLE CENTER GRID SEARCH
PHIDG = FRICTION ANGLE FOR START AND EXIT SLOPE (45-PHI/2)
XLEFT XRGHT ZBOTM XCNTR ZCNTR XZSTP PHIDG

Combined Surface Type 3 is generated by the same procedure as Type 2. However, two differences exist :

1. The part to the left of the middle circle centre is a straight line, i.e. from point 1 to point 2 on Figure 4.3.1.

2. Point 3 is found using the Type 2 procedure. The shear surface shape between points 2 and 3 is assumed as a cantilevered beam, clamped at point 2 and with known displacement and rotation at point 3.

The user is requested to give the same values as for Combined Surface Type 2 above.

Plane Shear Surfaces (Earth Pressure Analysis Only)

The user has selected 4 on the shear surface type menu. This request will only be accepted if the problem to be analysed is an earth pressure problem, i.e. IDTYP in the Control Section was given as 2.

For earth pressure problems the user must specify the safety factor to be used. Before reading the shear surface type specification, BEAST therefore asks :

EARTH PRESSURE PROBLEM , GIVE SAFETY FACTOR (ACTIVE+/PASSIVE-)

Note that the sign of the given safety factor will decide if the earth pressure computed at the last slice is an active or a passive earth pressure.

BEAST then reads the shear surface type identification (=4) and asks :

GIVE EP-PLANE ANGLES (DEGRS)
FIRST LAST STEP

where FIRST is the start inclination of the shear plane, LAST is the end inclination and STEP is the increment value. A STEP value smaller than 1.0 degree is replaced by 1.0 degree. If FIRST is greater than LAST, the two values are interchanged.

BEAST makes a trace print of the different shear planes analysed with computed values of earth pressure forces, position of the line of thrust and solution score. When completed, program control is returned to CDP.

Example of BEAST / User Interaction

The next page shows the interactive communication between the program and the user for the demonstration input file example, Section 4.2.

The replies given by the user are shown in **large bold** type. The operations are :

1. BEAST asks if instructions are needed and if an echo print of input data shall be made.
2. User requests general shear surface no. 1 with no shifts and no stretching.
3. BEAST computes safety factor and solution score.
4. User does not want another shear surface.

```
*****************************************************************
I                                                               I
I                        PROGRAM BEAST                          I
I                                                               I
I    SLOPE STABILITY / BEARING CAPACITY / EARTH PRESSURES       I
I                                                               I
I                Program Version : 21 Apr 2003                  I
I                                                               I
*****************************************************************

AUTHORIZED USER :                    DELIVERED AND SERVICED BY :

AutoGRAF/PostoGRAF                   Carl J Frimann Clausen
c/o AB Programbyggarna LLAS          Cidex 424 bis
S-17148 Solna                        F-06330 Roquefort les Pins
Phone   : (+46) (0)827 6990          Phone  : (+33) (0)493 775 275
Fax     : (+46) (0)827 6950          Fax    : (+33) (0)493 771 979
E-mail  : pb@programbyggarna.se      E-mail : cjfc@gf-net.com

THIS RUN WAS STARTED :  23 APR 2003  AT  15:05:48 HOURS

DO YOU NEED INSTRUCTIONS (Y/N) .................. N
SHALL ECHO PRINT OF INPUT DATA BE MADE (Y/N) .... N
INPUT FILE TEXT LINES ARE :
BEAST  PROGRAM DOCUMENTATION REPORT  SECTION 4.2  TEST EXAMPLE
SLOPE WITH SURFACE LOADING    11 Apr 2003

    STABILITY/BEARING PROBLEM TYPE
    EFFECTIVE STRESS ANALYSIS

    Solution Method : 0 BEAST 1988-2002

  1 GENERAL SHEAR SURFACES            0 SOIL NAILS

PRESENT CONTROL DATA ARE :
CRTSCR    R1     R2     R3    H3(1)   H3(2)  JPRINT  JPLOT NUMSLC
 2.000  0.000  1.000  0.000   0.000   0.000     0      2     0


----- PROGRAM CONTROL IS AT CENTRAL DECISION POINT
----- SPECIFY NEXT OPERATION PLEASE
-----   1 : TRY A NEW SHEAR SURFACE
-----   2 : PRINT LAST SURFACE DATA TO FILE NF16
-----   3 : SAVE  LAST SURFACE FOR POST PROCESSOR
-----   4 : PRINT BEST SURFACE DATA TO FILE NF16
-----   5 : SAVE  BEST SURFACE FOR POST PROCESSOR
-----   6 : READ CONTROL DATA MODIFICATIONS
-----   7 : HELP !
-----   8 : TERMINATE
.....   1


GIVE SURFACE TYPE (1=GENERAL 2=CIRCLE 3=COMBINED 4=EP-PLANE) .... 1

GIVE GENERAL SURFACE NUMBER AND MODIFICATION INSTRUCTIONS
 NUM  X-SHIFT  Z-SHIFT   X-MULT  Z-MULT
  1     0.000    0.000   1.000   1.000  = PRESENT VALUES
  /

++++ SAFETY FACTOR =   1.535   SCORE =  0.132   R-FACTOR =  1.000   SURFACE =  1

SHALL NEW GENERAL SURFACE BE TRIED (Y/N)..... N
```

4.4 Printed Results File NF16

When BEAST control is at the Central Decision Point, the user may request that a shear surface is printed, i.e. the data for that surface stored on file NF16 which may be printed after run termination. The user may print two different surfaces, either the last surface analysed, or the "best" surface so far, defined as :

* For bearing capacity and slope stability problems, the shear surface that has the lowest safety factor.

* For active earth pressure cases, the shear surface that has the highest E2 force at last slice.

* For passive earth pressure cases, the shear surface that has the lowest E2 force at last slice.

The next pages show the results printed to file NF16 for the input file demonstration example shown on Figure 4.2.1. User/program interaction for this case was given in Section 4.3.

A sketch of pore-water-pressures computed at the mesh nodal points is included at the start of file NF16, as JPLOT = 2 was specified on the input file.

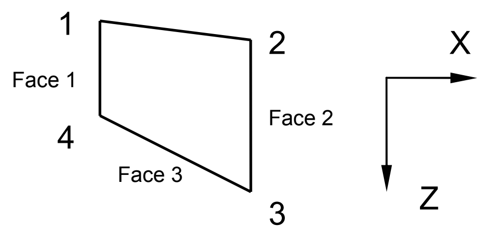
The values given in the surface summary table have the following meaning :

Stresses/Forces

The results shown are forces (not stresses). If the user wants output of stresses instead, the input parameter IPRTTP must be changed from 1 to 2.

Co-ordinates

The slice X- and Z- co-ordinates shown refer to this slice corner point numbering sketch.



WXT and WZT Forces

The forces WX and WZ acting at the slice centre (see Figure 3.6.1) include self weight, external loading and known PWP forces against the slice faces 1, 2 and 3. The forces listed (WXT and WZT) have been corrected for the PWP contributions, and can be considered as "total" forces :

$$WXT = WX - U1 + U2 - U3 * \sin(BETA) \quad (4.4.1)$$

$$WZT = WZ + U3 * \cos(BETA) \quad (4.4.2)$$

where U1, U2 and U3 are the integral of PWP against the slice faces 1, 2 and 3.

In our example WXT will thus for each slice be the resultant of given horizontal loading and computed horizontal water pressure against the soil surface. WZT will be the sum of self weight and vertical water pressure against the soil surface.

P- and S- forces

Effective normal force and shear force against the shear surface at slice bottom, see Figure 3.6.1.

E2- and T2- forces

Effective normal force and shear force against face 2, i.e. the vertical interface at the right side of the slice.

U2- and U3- forces

Average pore-water-forces against slice faces 2 and 3.

Rough

Interslice roughness value R computed at face 2. A value of 1.0 means that the Mohr-Coulomb strength at the interface is fully mobilised.

T2 = R * (C2*Z23 + E2*tan(PHI2)) / SF (4.4.3)

H2/Z23 and H3/L34

Position of the normal forces against faces 2 and 3. Value 0.0 means that the normal force acts at slice corner 3, value 1.0 at the opposite end of the face.

Warnings

In case of a negative normal stress, or a normal force outside its face, or too high roughness values, BEAST will print

WARNINGS = N

at the end of the slice line. N is number of problems identified for the slice.

Soil Nail Results

Printed results for cases that include soil nails are described in Appendix D. Example output is given in example no. 12 in Appendix C.

```
# BEAST  Output   Program Version = 16 Apr 2003    Time = 17 APR 2003  09:19:02

 BEAST  PROGRAM DOCUMENTATION REPORT  SECTION 4.2  TEST EXAMPLE
 SLOPE WITH SURFACE LOADING    11 Apr 2003


 +000 +000  +000 +000 +000  +000 +000 +000  +000

 +019 +019  +026 +032                            +000
                      +039  +046 +041
 +076 +076  +092                      +035  +026      +000
                 +108 +124
 +133 +133  +158            +140                 +071       +060
 +190 +190       +183            +147 +155
                      +204                  +161      +119       +132
            +199            +234                 +203       +178
                 +225            +254                                 +194
                      +268            +275            +247       +236
                            +310            +296                            +250 +250 +250  +250 +250
                                 +338            +335       +296      +279
                                      +366            +376       +346       +325 +325 +325  +325 +325
                                            +393                      +373
                                                            +418            +400 +400 +400  +400 +400
                                                 +418            +444
                                                      +443            +454  +475 +475 +475  +475 +475
                                                            +460
                                                                 +496 +523  +550 +550 +550  +550 +550


 POINTS =  95  MIN/MAX VALUES =   0.000E+00   5.500E+02   FACTOR =  1.0E+00

# BEAST  Output   Program Version = 16 Apr 2003    Time = 17 APR 2003  09:19:02

 BEAST  PROGRAM DOCUMENTATION REPORT  SECTION 4.2  TEST EXAMPLE
 SLOPE WITH SURFACE LOADING    11 Apr 2003

 =====================================================  SAFETY FACTOR =   1.535
 SURFACE NO :   1     SUMMARY OF GEOMETRY AND FORCES
 =====================================================  SOLUTION SCORE=   0.132

 SURFACE TYPE = GENERAL        X-START   Z-START    X-END   Z-END
                               24.000    20.000   152.000  60.000

 SOLUTION METHOD = BEAST 1988-2002 / EFFECTIVE STRESS ANALYSIS

 SLICE     X1      Z1      Z2     WXT-FRC    P-FRC      E2-FRC     U2-FRC    ROUGH  H2/Z23
           X2      Z4      Z3     WZT-FRC    S-FRC      T2-FRC     U3-FRC           H3/L34

   1     26.50   20.00   20.00   2.000E+01  1.219E+03  7.713E+02  1.144E+03  0.161  0.283
   1     34.00   25.00   40.00   1.913E+03  7.747E+02  9.877E+01  1.287E+03         0.412

   2     34.00   20.00   20.00  -1.634E-13  7.437E+03  2.253E+03  3.497E+03  0.492  0.225
   2     60.00   40.00   53.00   1.370E+04  2.449E+03  6.488E+02  6.035E+03         0.461

   3     60.00   20.00   20.00  -1.756E-13  7.608E+03  3.511E+03  5.181E+03  0.671  0.237
   3     80.00   53.00   61.00   1.434E+04  2.452E+03  1.030E+03  6.444E+03         0.482

   4     80.00   20.00   43.63  -3.720E+02  1.079E+04  4.406E+03  6.502E+03  0.858  0.361
   4    115.00   61.00   70.00   2.444E+04  3.514E+03  1.296E+03  1.326E+04         0.536

   5    115.00   43.63   60.00  -2.753E+03  4.350E+03  1.959E+03  1.716E+03  0.968  0.686
   5    140.00   70.00   66.00   1.269E+04  2.378E+03  1.036E+03  9.142E+03         0.605

   6    140.00   60.00   60.00   8.749E-14  2.093E+03  1.579E-13  2.500E-01  0.000  0.500
   6    152.00   66.00   60.00   3.756E+03  1.144E+03 -8.222E-12  3.837E+03         0.666
```

```
# BEAST  Output   Program Version = 16 Apr 2003    Time = 17 APR 2003  09:19:02

 BEAST  PROGRAM DOCUMENTATION REPORT  SECTION 4.2  TEST EXAMPLE
 SLOPE WITH SURFACE LOADING    11 Apr 2003

 SURFACE NO:  1  TYPE: GENERAL   SAFETY-FACTOR:  1.535   SCORE:  0.132
 BELOW SKETCH SHOWS SHEAR SURFACE WITH SLICE DIVISIONS AND MATERIAL ID-S

 1   1              1          1
 1   1              1          1
     1              1          1
     1              1          1
   1 1              1          1
     1              1          1
     1              2          2
                    2          2                  2
            2       2          2                  2
                    2          2                  2
                    2          2                  2
                         2     2                  2
                               2                  2             3      3
                               2                  2             3   3
                                         2        2             3
                                                  2      3
  01        02           03              04              05         06

  MAT GAMTOT SUA/SU0 SUD/SU0 SUP/SU0 COHESN PHIANG PHIRED RU-FCT  B-FCT  K-NOT B-SIG2 D/SU(B)
    1 18.000  1.000   1.000   1.000  20.000  35.00  0.00  0.000   0.000  0.000  0.000  0.000
    2 21.000  1.000   1.000   1.000  10.000  25.00  0.00  0.000   0.000  0.000  0.000  0.000
    3 21.000  1.000   1.000   1.000   0.000  40.00  0.00  0.000   0.000  0.000  0.000  0.000

# BEAST  Output   Program Version = 16 Apr 2003    Time = 17 APR 2003  09:19:02

 BEAST  PROGRAM DOCUMENTATION REPORT  SECTION 4.2  TEST EXAMPLE
 SLOPE WITH SURFACE LOADING    11 Apr 2003

 SURFACE NO:  1  TYPE: GENERAL   SAFETY-FACTOR:  1.535   SCORE:  0.132
 BELOW SKETCH SHOWS EFFECTIVE NORMAL STRESSES: P=SHEAR-SURFACE  E=INTER-SLICE
                                              U=RESULTING PWP AT SHEAR SURFACE

  01        02           03              04              05         06
 ------------------------------------------------------------------------ZERO
 I                                                                     I
 I                                                                     I
 I   E                                                                 I
 I                                                                     I
 I P                E                                                  I
 I U                           E                                       I
 I                                                                     I
 I                                                                     I
 I                                                                     I
 I                                                                     I
 I                                                                  P  I
 I                                                E      P             I
 I                                                                     I
 I                                                                     I
 I          U                                                          I
 I                                                                     I
 I                                                                     I
 I          P                                                          I
 I                                                                     I
 I                                                                  U  I
 I                       U               P                             I
 I                                                                     I
 I                                                              E      I
 I                                                                     I
 I                       P               U               U             I
 ------------------------------------------------------------------------SIGMAX

 P-MIN =  7.270E+01       P-MAX =  3.532E+02
 E-MIN =  3.856E+01       E-MAX =  3.265E+02
 U-MIN =  7.675E+01       U-MAX =  3.670E+02

 THIS RUN WAS TERMINATED :  17 APR 2003  AT  09:19:02 HOURS

 TIME USED =      0 SECONDS
```

4.5 Printed Results File NF17

This file contains detailed geometry and calculated results for individual shear surfaces and soil nails, if present. These values are intended to be used as input to a post processing program that may generate plots of the case analysed and the computed results.

The last page in this section shows the results printed for the Figure 4.2.1 demonstration example.

The values given have the following meaning :

NUMSRF =	Surface number
NTYP =	Shear surface type, 1 : General 2 : Circle 3 : Combined 4 : Plane
NUMSLC =	Number of slices
METHOD =	Solution method used, see Appendix E
IDEFTO =	1 : Effective stress 2 : Total stress 3 : Combined analysis
NNAILS =	Number of soil nails
MISC1-5 =	Miscellaneous integer input values, see Section 4.2
SAFETY.FCT =	Calculated safety factor
SCORE =	Solution score value
R-FACTOR =	Factor that the initial interslice roughness values Ro have been multiplied by
VALMSC1-5 =	Miscellaneous real input values, see Section 4.2

The values contained in array STORE(1-10) depend upon the type of shear surface :

General Surface

STORE(1) = X-coord shear surface start point
STORE(2) = Z-coord shear surface start point
STORE(3) = X-coord shear surface end point
STORE(4) = Z-coord shear surface end point

Circle

STORE(1) = X-coord circle centre
STORE(2) = Z-coord circle centre
STORE(3) = Circle radius
STORE(4) = Sum stabilizing moments
STORE(5) = Sum driving moments

Combined Surface Type 1

STORE(1) = X-coord start point
STORE(2) = X-coord circle centre
STORE(3) = Z-coord circle centre
STORE(4) = Circle radius
STORE(5) = Shear surface exit angle, degrees

Combined Surface Type 2 & 3

The below notation corresponds to Figure 4.3.1.

STORE(1) = XLEFT
STORE(2) = XRGHT
STORE(3) = ZBOTM
STORE(4) = XCNTR
STORE(5) = ZCNTR
STORE(6) = 45 - PHIDG/2
STORE(7) = 1.5 for Type = 2 (Circles), = 2.5 for Type = 3 (Cantilevered beam shape)

"GEOMETRY AND INITIAL ROUGHNESS" have the following meaning :

X2 X-coord slice upper right corner
Z2 Z-coord slice upper right corner
Z3 Z-coord slice lower right corner
X5 X-coord slice centre
Z5 Z-coord slice centre
Ro Initial face 2 roughness value

"SOIL STRENGTHS AND PWP" have the following meaning :

C2 Su or cohesion face 2
C3 Su or cohesion face 3
TAN2 tan(PHI) face 2
TAN3 tan(PHI) face 3
U2 Pore water pressure force face 2
U3 Pore water pressure force face 3

"CALCULATED FORCES AND ROUGHNESS" have the following meaning :

P Effective normal force at slice bottom
S Shear force at slice bottom
E2 Effective normal force against face 2
T2 Vertical shear force at face 2
SS Side shear force
R Roughness value at face 2

"CENTER LOADS AND MOMENT ARMS" have the following meaning :

WX+SNX Horizontal resulting force through slice centre
WZ+SNZ Vertical resulting force through slice centre
WM+SNM Moment at slice centre
H2 Moment arm of force E2 w.r.t. corner point 3
H3 Moment arm of force P w.r.t. corner point 3
HS Moment arm of force SS w.r.t. corner point 3

SNX, SNZ and SNM are the forces and moments from the soil nails, see Appendix D. The three moment arms H2, H3 and HS are shown on Figure 3.6.1. If piles and/or soil nails are present, two additional result tables are included, see example 12 in Appendix C.

In case of combined analysis, an extra result table with effective stress and total stress shear forces are included at the end of file NF17.

```
# BEAST  Output   Program Version = 21 Apr 2003    Time = 23 APR 2003  15:05:48
 BEAST  PROGRAM DOCUMENTATION REPORT  SECTION 4.2  TEST EXAMPLE
 SLOPE WITH SURFACE LOADING    11 Apr 2003

 NUMSRF  NTYP  NUMSLC  METHOD  IDEFTO  NNAILS  MISC1 MISC2 MISC3 MISC4 MISC5
    1      1      6       0       1       0      0     0     0     0     0
 SAFETY.FCT  SCORE  R-FACTOR   VALMSC1  VALMSC2  VALMSC3  VALMSC4  VALMSC5
   1.5349    0.132   1.000      0.000    0.000    0.000    0.000    0.000

   2.4000E+01  2.0000E+01  1.5200E+02  6.0000E+01  0.0000E+00 STORE(1,2,3,4,5)
   0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 STORE(6,7,8,9,10)

 GEOMETRY AND INITIAL ROUGHNESS
 SLICE  X2          Z2          Z3          X5          Z5          R0
   0   2.6500E+01  2.0000E+01  2.5001E+01
   1   3.4000E+01  2.0000E+01  4.0000E+01  3.1000E+01  2.7000E+01  5.9761E-02
   2   6.0000E+01  2.0000E+01  5.3000E+01  4.8063E+01  3.3516E+01  2.6693E-01
   3   8.0000E+01  2.0000E+01  6.1000E+01  7.0360E+01  3.8572E+01  4.2629E-01
   4   1.1500E+02  4.3625E+01  7.0000E+01  9.6234E+01  4.8066E+01  7.0518E-01
   5   1.4000E+02  6.0000E+01  6.6000E+01  1.2488E+02  5.9257E+01  9.0438E-01
   6   1.5200E+02  6.0000E+01  6.0001E+01  1.4400E+02  6.2000E+01  0.0000E+00
 SOIL STRENGTHS AND PWP
 SLICE  C2          C3          TAN2        TAN3         U2          U3
   1   2.0000E+01  2.0000E+01  7.0021E-01  7.0021E-01  1.1439E+03  1.2871E+03
   2   1.7500E+01  1.0000E+01  6.4173E-01  4.6631E-01  3.4969E+03  6.0355E+03
   3   1.2500E+01  1.0000E+01  5.2478E-01  4.6631E-01  5.1810E+03  6.4436E+03
   4   1.0000E+01  1.0000E+01  4.6631E-01  4.6631E-01  6.5019E+03  1.3264E+04
   5   0.0000E+00  0.0000E+00  8.3910E-01  8.3910E-01  1.7160E+03  9.1421E+03
   6   0.0000E+00  0.0000E+00  8.3910E-01  8.3910E-01  2.5001E-01  3.8370E+03
 CALCULATED FORCES AND ROUGHNESS
 SLICE  P           S           E2          T2          SS          R
   1   1.2192E+03  7.7469E+02  7.7130E+02  9.8769E+01  0.0000E+00  1.6127E-01
   2   7.4374E+03  2.4489E+03  2.2532E+03  6.4879E+02  0.0000E+00  4.9214E-01
   3   7.6084E+03  2.4518E+03  3.5115E+03  1.0300E+03  0.0000E+00  6.7125E-01
   4   1.0791E+04  3.5138E+03  4.4061E+03  1.2957E+03  0.0000E+00  8.5782E-01
   5   4.3504E+03  2.3783E+03  1.9589E+03  1.0361E+03  0.0000E+00  9.6753E-01
   6   2.0925E+03  1.1439E+03  1.5793E-13 -8.2224E-12  0.0000E+00  0.0000E+00
 CENTER LOADS AND MOMENT ARMS
 SLICE  WX+SNX      WZ+SNZ      WM+SNM      H2          H3          HS
   1   2.7302E+01  1.3369E+03  3.9468E+02  5.6635E+00  6.9053E+00  0.0000E+00
   2   3.4613E+02  8.2974E+03  2.5517E+03  7.4277E+00  1.3414E+01  0.0000E+00
   3   7.0901E+02  8.3560E+03  1.9699E+03  9.7284E+00  1.0382E+01  0.0000E+00
   4   1.6103E+03  1.1592E+04  1.4607E+04  9.5294E+00  1.9377E+01  0.0000E+00
   5   5.8849E+02  3.6605E+03 -8.5732E+02  4.1183E+00  1.5315E+01  0.0000E+00
   6  -1.3034E-13  3.2405E+02 -2.7285E-12  5.0000E-04  8.9411E+00  0.0000E+00
```

4.6 Warnings and Error Messages

BEAST carries out a rather detailed check of input data, intermediate results and the final solution. If a problem is identified, BEAST may :

- Print an error message to the user's screen and ask if the run shall be continued or terminated.

- Print a warning message to the file BEAST.LOG and continue the data processing.

Warnings and error messages can conveniently be divided into two groups :

Input Data Errors

Problems encountered when reading input data file NF15, either format type errors, or logical errors. Error / warning messages will be generated by subroutines READ and MESH.

Execution Errors

Problems encountered during processing of a given shear surface. Error / warning messages may be generated by several subroutines.

In addition to these primary messages, secondary messages are generated as control is passed up through the calling routines after an error condition occurred.

Many of the error and warning messages are self explanatory and are not included below. Other messages may need additional explanation and a proposal for corrective actions. By means of the Central Decision Point HELP option, the user may display sections 1 and 5 of the HELP.BST text file. These two sections contain the "Input Data Error Codes" and the "Execution Error Messages" respectively.

The remaining pages of this section show these codes and error messages together with explanations as contained on the HELP.BST file.

```
INPUT DATA ERROR CODES
**********************

READ : ID = 100     'CONFRC,CONLTH' WAS ATTEMPTED READ
READ : ID = 200     'FCTSU,FCTTAN' WAS ATTEMPTED READ
READ : ID = 500     'IDTYP' WAS ATTEMPTED READ
READ : ID = 600     'IDEFTO' WAS ATTEMPTED READ
READ : ID = 700     'NUMGEN' WAS ATTEMPTED READ
READ : ID = 800     'NUMSLC' WAS ATTEMPTED READ
READ : ID = 900     'SIDSHR' WAS ATTEMPTED READ
READ : ID = 1200     VALUES FOR H3-ASSUMPTION WAS ATTEMPTED READ
READ : ID = 1300     VALUES FOR R-ASSUMPTION WAS ATTEMPTED READ
READ : ID = 1310     'ITENSP' WAS ATTEMPTED READ
READ : ID = 1320     'ITENSE' WAS ATTEMPTED READ
READ : ID = 1350     'JPRINT' WAS ATTEMPTED READ
READ : ID = 1360     'IPRTTP' WAS ATTEMPTED READ
READ : ID = 1370     'JPLOT' WAS ATTEMPTED READ
READ : ID = 1400     'CRTFRC' WAS ATTEMPTED READ
READ : ID = 1450     'CRTSCR' WAS ATTEMPTED READ
READ : ID = 2200     WALL SPECIFICATIONS WAS ATTEMPTED READ
READ : ID = 2500     'NUMMAT' WAS ATTEMPTED READ
READ : ID = 2600     'NUMXSU' WAS ATTEMPTED READ
READ : ID = 2700     'NODSU' WAS ATTEMPTED READ
READ : ID = 2800     'CRACKZ' WAS ATTEMPTED READ
```

```
READ : ID = 2900     'CRACKW' WAS ATTEMPTED READ
READ : ID = 2950     'PHIREF' WAS ATTEMPTED READ
READ : ID = 3000+N   EFFECTIVE STRESS MATERIAL PROP WAS ATTEMPTED READ
READ : ID = 3049     UNDR EFF STRESS ANALYSIS NOT ALLOWED FOR EARTH PRESS CASE
READ : ID = 3050+N   TOTAL STRESS MATERIAL PROP WAS ATTEMPTED READ
READ : ID = 3100+N   SU-VALUES WITH DEPTH WAS ATTEMPTED READ
READ : ID = 3200+N   SU-VALUES AT INDIVIDUAL NODES WAS ATTEMPTED READ
READ : ID = 3250     SU-VALUES AT ALL NODES WAS ATTEMPTED READ
READ : ID = 3300     'IDPWP' WAS ATTEMPTED READ
READ : ID = 3350     UNDR EFF STRESS ANALYSIS NOT COMPATIBLE WITH HYDROSTAT PWP
READ : ID = 3400     'NUMXPW' WAS ATTEMPTED READ
READ : ID = 3420     'NODPWP' WAS ATTEMPTED READ
READ : ID = 3425     'FCTNOD' WAS ATTEMPTED READ
READ : ID = 3430     'WATERZ' WAS ATTEMPTED READ
READ : ID = 3440     'GAMWAT' WAS ATTEMPTED READ
READ : ID = 3450     'GAMPWP' WAS ATTEMPTED READ
READ : ID = 3470     'PWPMIN' WAS ATTEMPTED READ
READ : ID = 3500+N   PWP VALUES AT VERTICAL SECTIONS WAS ATTEMPTED READ
READ : ID = 3700+N   PWP VALUES AT INDIVIDUAL NODES WAS ATTEMPTED READ
READ : ID = 3750     PWP VALUES AT ALL NODES WAS ATTEMPTED READ
READ : ID = 4100     'NUMPNT' WAS ATTEMPTED READ
READ : ID = 4200     'NUMSIG' WAS ATTEMPTED READ
READ : ID = 4250     'SIGTOP' WAS ATTEMPTED READ
READ : ID = 4260     'XTOP1,XTOP2' WAS ATTEMPTED READ
READ : ID = 4300     'FCTPNT,FCTSIG' WAS ATTEMPTED READ
READ : ID = 4500     'ACCXRT,ACCZRT' WAS ATTEMPTED READ
READ : ID = 4700+N   POINT FORCE VALUES WAS ATTEMPTED READ
READ : ID = 4800+N   SURFACE DISTRIBUTED LOADS WAS ATTEMPTED READ
READ : ID = 4900+N   GENERAL SHEAR SURFACE 'N' CONTROL DATA WAS ATTEMPTED READ
READ : ID = 5000+N   GENERAL SHEAR SURFACE 'N' X-COORDS WAS ATTEMPTED READ
READ : ID = 5100+N   GENERAL SHEAR SURFACE 'N' Z-COORDS WAS ATTEMPTED READ

                          N O T I C E

      GENERAL SURFACE PWP/SIGMAN/TAU LINES SHALL ONLY BE IN-
      CLUDED IF NON-HYDROSTATIC PWP WAS SPECIFIED.  IN ADDITION,
      PROGRAM ASKS IF THE 'SIGMAN' AND 'TAU' VALUES SHALL BE
      READ.  IF NOT INCLUDED , THEY ARE CALCULATED ASSUMING
      HORIZONTAL SOIL SURFACE.

      NUMBER OF VALUES TO BE GIVEN DEPENDS UPON THE INPUT
      VALUE OF 'NUMSLC' :

           NUMSLC = 0    READ ONE VALUE AT EACH SLICE BOTTOM CENTER
           NUMSLC = N    READ ONE VALUE AT EACH SHEAR SURFACE POINT

READ : ID = 5200+N   GENERAL SHEAR SURFACE 'N' PWP-VALUES WAS ATTEMPTED READ
READ : ID = 5300+N   GENERAL SHEAR SURFACE 'N' INITIAL SIGMA-N WAS ATTMPTD READ
READ : ID = 5400+N   GENERAL SHEAR SURFACE 'N' INITIAL TAU WAS ATTEMPTED READ
MESH : ID = 200  NUMXLN WAS ATTEMPTED READ
MESH : ID = 300  NUMELZ WAS ATTEMPTED READ
MESH : ID = 350  NUMLAY WAS ATTEMPTED READ
MESH : ID = 400  NUMTRI WAS ATTEMPTED READ
MESH : ID = 500 + N  X-LINES WITH SURFACE AND ROCK WAS ATTEMPTED READ
MESH : ID = 600 + N  NODAL POINT MODIFICATION LINE WAS ATTEMPTED READ
MESH : ID = 700 + N  ELEMENT MATERIAL MODIFICATION LINE WAS ATTEMPTED READ
MESH : ID = 750 + N  HORIZONTAL LAYER DATA WAS ATTEMPTED READ
MESH : ID = 800 + N  MATERIAL TRIANGLES WAS ATTEMPTED READ


EXECUTION ERROR MESSAGES AND WARNINGS
*************************************

BUILD  : ERROR FROM SR/XXXXXX   NS,XX,ZZ,BETA,IERR=
          NS      : Slice number
          XX,ZZ   : Point co-ordinates
          BETA    : Shear surface inclination , radians
          IERR    : Set by SR/XXXXXX

BUILD  : NEGATIVE WEIGHT    N,WZ,U3 =
          N       : Slice number
          WZ      : Vertical resulting force at slice centre
          U3      : PWP force at slice bottom
```

```
BUILD  : NS,MAT,PWPB,TANPHI
          Zero friction angle not allowed for UESA type solution.

CHKEQL : SUM FRC-X ERROR     N,SUMX,EPSFRC
           Equilibrium problem in X-direction
           N      : Slice number
           SUMX   : Sum of X-forces
           EPSFRC : Check criteria used

CHKEQL : SUM FRC-Z ERROR     N,SUMZ,EPSFRC
           Equilibrium problem in Z-direction
           N      : Slice number
           SUMZ   : Sum of Z-forces
           EPSFRC : Check criteria used

CHKEQL : SUM MOMENTS ERROR     N,SUMM,EPSMOM
           Moment equilibrium problem
           N      : Slice number
           SUMM   : Sum of moments
           EPSMOM : Check criteria used

CHKEQL : S-FORCE ERROR       N,SCMP,S(N)
           Strength mobilisation on shear surface problem
           N      : Slice number
           SCMP   : S-force calculated by SR/CHKEQL
           S(N)   : S-force calculated during solution process

CHKEQL : E2-FORCE LAST SLICE      E2(NUMSLC),CRTFRC
           Horizontal force at last slice is not zero

CHKEQL : T2-FORCE LAST SLICE      T2(NUMSLC),CRTFRC
           Vertical shear force at last slice is not zero

COMLOW : IERR = 1   Big circle centre above base bottom
              = 2   Big circle centre outside base right edge
              = 3   Surface type i.d. is not 1 or 2

COMSRF : IERR = 1   Negative square root argument
              = 2   Zero division attempted
              = 3   Angle BETA less than 1 degree
              = 4   A geometry problem was identified

COMSRF : PROBLEM     XS,ZS,XC,ZC,R,BETA,IERR,ID =
           XS,ZS  :  Start point co-ordinates
           XC,ZC  :  Circle centre
           R      :  Circle radius
           BETA   :  Exit angle, radians
           ID     :  Internal location i.d.

ECHO   : NFR,NFW,NOW,MAX =
           Error during reading of formatted input file
           NFR    :  Unit number reading
           NFW    :  Unit number writing
           NOW    :  Present line number
           MAX    :  Maximum allowed lines on file NFR

FRCEQR : IERR = 1   Zero or negative division attempted for P
                    force
              = 2   Error in SR/ROOT1
              = 3   Non-converging solution

FRCEQR : P-FORCE PROBLEM , TOO STEEP SHEAR SURFACE EXIT ANGLE ?
         SF  SLICE  SIN(BETA)  TAN(PHI2)  TAN(PHI3)  ROUGHNESS  DIV
           The user should consult Section 3.7 of the program
           documentation report.

FRCEQR : WARNING FROM SR/FRCEQR : LARGE SAFETY FACTOR
         Equilibrium is obtained without shear stresses along the
         shear surface.  Check if loads are zero.

FRCEQR : NON-CONVERGING SOLUTION   ITNOW =
           SF that gives E2=0.0 at last slice could not be found,
           see Figure 3.7.1 in program documentation report.
```

```
GEOMET : IERR = 1      No intersections soil/shear surface
              = 2      One intersection only
              = 3      Wall position outside shear surface (Earth
                       pressure problem)
              = 4      Soil surface points not in increasing X
                       order
              = 5      Shear surface points not in increasing X
                       order
              = 10+N   SR/INTPOL problem , soil surface
              = 20+N   SR/INTPOL problem , shear surface
              = 30+N   SR/INTPOL problem , rock surface
              = 100+N  Zero or negative area slice N
              = 200    Problem with horizontal layers intersection
              = 200+N  SR/INTPOL problem , new slice generation
              = 299    Number of slices exceed 99
              = 300+N  SR/INTPOL problem when genrt. last slice
              =  -N    Geometry problem slice N

HELP   : ERROR DURING FILE OPENING    IERR = N
           Value N gives I/O status and was set by Fortran-77

INTPOL : IERR = 1  Value of INCR is not +1 or -1
              = 2  X-values not in increasing order
              = 3  X-values not in decreasing order
              = 4  Value of MAX is less than 1 or greater than 400

INTPRF : IERR = 1  Number of X-lines less than 1
              = 2  Number of Z-points less than 1
              = 3  Maximum allowed Z-points less than 1
              = 4  Too many Z-points
              = 5  X-lines not in increasing X order
              = 6  Z-points not in increasing Z order

LOADER : IERR = N      Value of N set in SR/LOCATE
              = 100+N  Value of N set in SR/INTPOL
              = 200+N  Slice area problem

LOADER : PROBLEM : SLICE AREA     NS,AREA(NS),A
           Mismatch between calculated slice areas
           NS        :  Slice number
           AREA(NS) :  Slice area calculated by SR/BUILD
           A         :  Slice area calculated by SR/LOADER

LOADER : PROBLEM : WATER PRESSURE ON SLICE TOP    NS,I,IERR
           NS        :  Slice number
           I         :  Slice corner point 1 or 2
           IERR      :  Set by SR/INTPOL

LOCATE : IERR = 1  Given point is located outside the mesh

LOCATE : PROBLEM :       IDM,XX,ZZ,ZZZ =
           IDM    = -1  Flags that element number is wanted
           IDM    =  N  Material number
           XX,ZZ  =     Given point co-ordinates
           ZZZ    =     Calculated Z at top of element column for given XX

MESH   : LAST X-LINE NUMX IS NOT ZERO     N,NUMX(N)
           The last given X-line (N) has NUMX(N) elements to next X-line.
           If N really is the last line, NUMX(N) shall be zero.

MESH   : NODE NUMBER PROBLEM      NODE,NUMNP
           The last generated node is not equal to number of nodes in the mesh

MESH   : NODE SHIFT SEQUENCE ERROR    NP1,NP2
           NP1 must be smaller than or equal to NP2

MESH   : NODE SHIFT POSITION ERROR   ND,Z(ND),Z(ND-1)
           ND  =  Node number
           Z(ND) must be smaller than Z(ND-1)

MESH   : SOIL LAYER DATA PROBLEM   I,ZLAST,BOTLAY(I),MAT
           Layer bottom Z values are not in increasing order
```

```
MESH   : MATERIAL TRIANGLES SEQUENCE ERROR    N,J,MATTRI(N)
           Triangles are not given in order 1,2,3,...

PAGES  : IERR = 1  Section number in call outside allowed range
              = 2  Section number read outside allowed range
              = 3  Page number read outside allowed range
              = 4  Too many lines on one page
              = 5  Page sequence error
              = 6  Section sequence error

PAGES  : ERROR   ID,IERR =
           IERR has values as shown above
           ID is a local position indicator
           For IERR=4 , ID is set to 100*SECTION + PAGE

PRINT  : GEOMETRY ERROR    SLICE,X3,X4 =
           X at slice corner 3 equal to or smaller than X at
           corner 4.  A storage error has occurred.

PWP    : IERR = 100+N   Value of N set by SR/PWPXZ

PWP    : PROBLEM WHEN COMPUTING GEN SURF PWP
         IERR,NS,XVALUE =
           IERR    : Set by SR/INTPOL
           NS      : Slice number
           XVALUE  : X-coord for which gen. surf. PWP was wanted

PWPXZ  : IERR = N       Value of N set by SR/LOCATE
              = N+100   Value of N set by SR/INTPOL
              = N+300   Value of N set by SR/INTPRF

READ   : NUMBER OF MATERIALS ERROR   NUMMAT,MATMAX
           NUMMAT is smaller than maximum material i.d. specified
           in the Geometry Section, MATMAX.

READ   : INPUT DATA CONTROL   ID =
           Logical error , see Input Data Error Codes

RMULT  : IERR = 1  Initial interslice roughness values Ro are all
                   zero, and CRTSCR is less than 1.0.

RMULT  : TOO HIGH R ?   REPEATED WITH R = 0.0
           Error from SR/FRCEQR (IERR=1) may be caused by too
           high R values.  Force equilibrium solution is
           calculated with R = 0.0.

ROOT1  : IERR = -1  Number of points negative or zero.
              =  1  XMAX is less than XMIN
              =  2  Zero division attempted
              =  3  YMAX is zero or negative

SETSF0 : IERR = -2  System analysed has very high safety factor
              =  N  Value of N set by SR/FRCEQR

SLV123 : IERR =  1  This routine generates a number of different
                     messages in case an error condition is detected

SOLVER : IERR =  N  Value of N set by routines called by SOLVER

SUXZ   : IERR =  N      Value of N set by SR/LOCATE
              =  100+N  Value of N set by SR/INTPRF

XYPLOT : SCALING-10 PROBLEM   VALMAX =

                     Maximum parameter value could not be scaled into
                     the rannge 100 to 1000.
```

5.0 PROGRAM MAINTENANCE

5.1 Subroutine Description and Control Flow

In addition to the below subroutines a main program will be needed. The minimum main program is :

```
PROGRAM BEAST
CALL CONTRL
END
```

Subroutine	Purpose	Called from	Calls subroutines
BEAST	Main program	-	CONTRL
BUILD	Computes slice forces independent of the safety factor. Sets values of material properties at slice faces.	SOLVER	LOCATE,SUXZ,PWP,LOADER, YESNO
CHKCMB	Combined analysis, checks and modifies the assumed governing strength case	FRCEQR RMULT	-
CHKEQL	Checks slice equilibrium and shear surface strength mobilisation	SOLVER	-
CIRC3P	Finds centre and radius of a circle that pass through 3 given points	SLV123	-
CIRCLE	Directs analyses of circular shear surfaces	CONTRL	CIRSRF,SOLVER,YESNO
CIRSRF	Computes co-ordinates along a circular arc	CIRCLE	-
COMBND	Directs analyses of combined shear surfaces	CONTRL	INTPOL,COMSRF,SOLVER, YESNO,COMLOW
COMLOW	Computes co-ordinates along a combined surface with circle centre below the surface	COMBND	-
COMSRF	Computes co-ordinates along a combined surface with circle centre above the surface	COMBND	-
CONTRL	Directs control flow. Handles interactive communication with the user.	BEAST	INPOUT,HEADER,TIMER0, TOPLIN,YESNO,HELP,READ, PRINT,GENRAL,CIRCLE, COMBINED,PLANE,POST
ECHO	Makes echo print of input file NF14 to result file NF16	READ	-
EQUAT2	Solution of a quadratic equation	SLV123	-
FRCEQR	Finds force equilibrium solution with given interslice roughness R	SOLVER RMULT SETSF0	ROOT1,CHKCMB
GENRAL	Directs analyses of general shear surfaces	CONTRL	GENSRF,SOLVER,YESNO
GENSRF	Computes modified co-ordinates for general surface	GENRAL	-

Subroutine	Purpose	Called from	Calls subroutines
GEOMET	Computes intersections between soil surface and shear surface. Computes slice corner co-ordinates etc.	SOLVER	INTPOL,YESNO,SORT2
HEADER	Prints start information to user's screen	CONTRL	-
HELP	Activates INSTRUCTION and HELP facilities	CONTRL	PAGES
INPOUT	Reads input parameter IPRTTP to check if input/output shall be via files INP and RES rather than the normal interactive use	CONTRL	-
INTBL1	Intersections between a broken line and a straight line	MODIFY NAILS	-
INTPOL	Linear interpolation between points with given(X,Y) co-ordinates	Several	-
INTPRF	Linear interpolation between vertical profiles with given parameter values	PWPXZ SUXZ	-
LOADER	Computes sums of forces and moments, acting upon a slice, that are independent of the safety factor	BUILD	TRILIN,INTPOL,LOCATE, STRIP,WATER
LOCATE	Finds soil material id or mesh element number for a given point (X,Z).	Several	TRIPNT
MESH	Reads geometry input data and generates the finite element type mesh	READ	SORT2,LOCATE,PWPXZ, SUXZ,XYPLOT
MODIFY	Checks and modifies shear surface exit angle	SOLVER	LOCATE,INTBL1,INTPOL
MOMEQL	Modifies the initial force equilibrium solution and calculates the unknown slice forces	RMULT SOLVER SLV123	YESNO,SOLABC
NAILS	Soil nail analysis, finds capacities	SOLVER	INTBL1
NAILSP	Print of calculated soil nail values	PRINT	TOPLIN
PAGES	Displays a section from a text file on the user's screen page by page	HELP	-
PLANE	Directs analyses of earth pressure cases with plane shear surfaces	CONTRL	SOLVER,YESNO
PLOT	Makes a text-type plot formatted for the line printer of shear surface values	PRINT	TIMER0,TOPLIN,LOCATE
POST	Generates printed output to file NF17 that may be used as input to a post-processor	CONTRL	TIMER0,TOPLIN
PRINT	Print of shear surface values to file NF16	CONTRL	TIMER0,TOPLIN,PLOT,NAILSP
PWP	Computes pore-water-pressure forces against the slice faces	BUILD	PWPXZ,INTPOL
PWPXZ	Finds pore-water-pressure at a point (X,Z)	MESH PWP	LOCATE,INTPOL,INTPRF
READ	Reads the input files NF14 and NF15	CONTRL	YESNO,ECHO,MESH,INTPOL, READSN

Subroutine	Purpose	Called from	Calls subroutines
READSN	Reads soil nails input values from file NF15	READ	-
RMULT	Finds the force equilibrium solution with the lowest score value	SOLVER	INTPOL,FRCEQR,MOMEQL, CHKCMB,SCORER,SORT2
ROOT1	Finds an expected root (Y=0.0) for a group of points (X,Y)	FRCEQR	SORT2
ROOT3	Revised version of ROOT1	SLV123	SORT2
SCORER	Calculates the score value for the present solution	RMULT SOLVER SLV123	-
SETSF0	Computes minimum and maximum safety factors that may be tried during the solution process	SOLVER	FRCEQR
SLV123	Solution routine for methods Bishop simpl., Bishop modified and BEAST 2003	SOLVER	CIRC3P,EQUAT2,ROOT3, MOMEQL,SCORER,CHKCMB
SOLABC	Solves the 3 governing non-linear equations	MOMEQL	-
SOLVER	Directs the solution process	CIRCLE COMBND GENRAL PLANE	GEOMET,MODIFY,BUILD, NAILS,SUCRCL,FRCEQR, MOMEQL,SCORER,UPDATE, SETSF0,RMULT,SLV123, CHKEQL,YESNO
SORT2	Sorts a group of points (X,Y) in order of increasing or decreasing X	Several	-
STRIP	Computes slice loading due to given surface distributed stresses	LOADER	-
SUCRL	Simplified solution in case of total stress analysis and circular shear surface	SOLVER	LOCATE
SUXZ	Computes undrained strength values Su0 and Su(beta) for a given point (X,Z)	BUILD MESH	LOCATE,INTPRF
TIMER0	Print of real time values	Several	TIMER1
TIMER1	Obtains real time values	TIMER0	System/compiler routines
TOPLIN	Prints program version and real time at the top of each output page	Several	-
TRIANG	Computes the area of a triangle with given corner co-ordinates	TRILIN	-
TRILIN	Computes the two areas of a triangle that is intersected by a horizontal line	LOADER	SORT2,TRIANG
TRIPNT	Decides if a given point (X,Y) is outside or inside a given triangle	LOCATE	-
UPDATE	Computes new values of PHI-angle for stress dependent friction angles and/or new PWP values in the case of UESA type solution	SOLVER	LOCATE,INTPOL

Subroutine	Purpose	Called from	Calls subroutines
WATER	Computes water pressure forces and moments against the top of a slice	LOADER	-
XYPLOT	Makes a plot on the line printer of a parameter value given at points (X,Y)	MESH	-
YESNO	Reads answer "Yes" or "No" from the user's keyboard	Several	-

5.2 Input / Output Files

BEAST needs a number of input/output files, see Figure 4.1.1. They have been named NF5, NF6, NF14, NF15, NF16, NF17 and NF18 internally in the program. The numerical values are set at the start of SR/CONTRL :

NFi = i

Unit : NF5 = 5

This is the user's keyboard or file INP. Replies to program requests are read from this unit.

Unit : NF6 = 6

This is the user's screen or file RES. Messages and requests are written to this unit.

Unit : NF14 = 14 Name : BEAST.INP

This is the formatted input file prepared by the user. This file may contain comment lines. The file is read and duplicated to file NF15 except for comment lines. An example file NF14 is given in Section 4.2. This section also contains a detailed description of file content.

This file must be present in the BEAST directory when the program is started.

Unit : NF15 = 15 Name : BEAST.TMP

BEAST reads the actual input values from this file. The file is generated from file NF14 at the start of SR/READ.

Unit : NF16 = 16 Name : BEAST.RES

This is the formatted print file that is generated by BEAST upon request from the user. Four types of data may be printed :

* Geometry and check data for the finite element type mesh generated, as well as a plot of PWP or Su0 values at the mesh nodal points.
* Geometry and forces or stresses for selected shear surfaces, either the best up to now, or the last surface analysed.
* A plot of values from the shear surface.
* Summary of soil nail results

The file is formatted for a line printer with at least 101 characters per line.

Unit : NF17 = 17 Name : BEAST.PLT

This is the post processor file. A complete set of values for selected shear surfaces, and soil nails if present, are stored formatted on this file.

Unit : NF18 = 18 Name : BEAST.LOG

The file was introduced in BEAST revision 4. Trace output and warning messages are printed to this file. It is recommended that the user checks the file contents before the results are accepted.

TEXT FILES

BEAST may read two text files INSTRUCT.BST or HELP.BST if requested by the user. Unit NF=19 is used for this purpose. The unit is opened just before reading, and it is closed when the user exits the INSTRUCT or HELP facility.

5.3 Program Modifications , Common Area

Common Blocks

All BEAST subroutines that need data stored in the common area, are using identical common blocks. These common statements are contained in a special file referred to as BEAST.CMN. The last pages of this section give the Fortran-77 source listing of this file.

At the time of compilation the common file is included into the individual subroutines by the statement :

```
INCLUDE 'BEAST.CMN'
```

Type Declarations

The examples given in this report were analysed with program BEAST working in double precision mode. The above common file contains the following type declaration statement :

```
IMPLICIT INTEGER*4(I-N) , REAL*8(A-H,O-Z)
```

General purpose routines do not need access to the common area. However, they do need a type declaration to avoid mixing of different number types. All such general routines therefore have the above IMPLICIT statement at the top.

Problem Size Modification

The maximum allowed problem sizes are listed at the start of the common file shown at the end of this section. In case any of these limits shall be modified, the following program changes are needed :

1. Change the variable in the common file to fit the new maximum size.
2. Update the common explanation lines as well.
3. In SR/CONTRL modify the maximum sizes set at the start of the routine.
4. Maximum values for material triangles and number of materials are checked in SR/MESH. Modify these checks if required.
5. Recompile and link all routines.

Type Modifications

If the program shall be used in single precision mode, the following modifications are needed :

1. Change the type statement in BEAST.CMN file.
2. Change the type statements in routines that do not use the BEAST.CMN file.
3. Change the single/double precision switch IDSPDP set at start of SR/CONTRL.
4. Recompile and link all routines.

Time Routines

Revision 2 of program BEAST uses subroutine TIMER to get values for date, clock time and connect time. The values are printed for information purposes only. If BEAST is installed on other machines than the one it was developed for (IBM PC AT), it may be necessary to replace or deactivate the DOS time routines called by SR/TIMER :

CALL GETDAT(IYEAR,IMONTH,IDAY)

CALL GETTIM(IHOUR,IMIN,ISEC,ISC100)

Revision 3 of program BEAST uses a set of modified calls and routines to obtain the time values. Subroutine TIMER has been renamed TIMER0, which calls a new routine TIMER1. This routine finds the wanted values using Lahey Fortran system routine calls :

CALL DATE (MMDDYY)

CALL TIME (HHMMSS)

If the program shall be compiled with a different Fortran compiler, these routines will need to be modified or replaced.

```
(001) C      PROGRAM BEAST COMMON FILE                                    common
(002) C                                                                   common
(003) C DATE          SIGN    LOG OF CORRECTIONS                          common
(004) C -----------   -----   ------------------------------------------  common
(005) C 28 JUN 1988   CJFC    BEAST / FORTRAN-77 PC VERSION               common
(006) C 15 JUL 1988   CJFC    INCLUDE VALUES FROM OLD SR/CONTRL IN /MASTER/    common
(007) C 09 AUG 1988   CJFC    SEVERAL MODIFICATIONS DUE TO NEW INPUT FILE      common
(008) C 15 AUG 1988   CJFC    MODIFY PWP INPUT BY X-LINES , SAME AS SU0        common
(009) C 18 AUG 1988   CJFC    STORE BEST SURFACE IN COMMON , NOT ON FILE NF7   common
(010) C 08 SEP 1988   CJFC    INCLUDE ID'S FOR ALLOWED P- AND E-FORCE TENSION  common
(011) C 13 SEP 1988   CJFC    D-PARAM FOR EACH SLICE , INITL STRESS GENRL SURF common
(012) C 20 SEP 1988   CJFC    INCLUDE ARRAY WITH GROUND WATER LEVEL            common
(013) C 29 SEP 1988   CJFC    REMOVE UNIT NF7 , NOT USED ANY LONGER            common
(014) C 24 OCT 1988   CJFC    INCREASE SIZE OF COMMON /BEST/                   common
(015) C 21 SEP 1991   CJFC    INCREASE NUMBER OF MATRL TRIANGLES FROM 10 TO 150common
(016) C 26 JUN 1992   CJFC    PLACE PROGRAM DATE IN COMMON /TEXT/              common
(017) C 01 OCT 1993   CJFC    INCLUDE STORAGE FOR SLICE SU-VALUES SU2 AND SU3  common
(018) C 04 OCT 1993   CJFC    KEEP REAL TIME VALUES IN ARRAY TIME(6)           common
(019) C 07 OCT 1993   CJFC    INCREASE MAX STRIP LOADS FROM 5 TO 20            common
(020) C 07 MAY 2000   CJFC    Common blocks split into INTEGER and REAL*8 part common
(021) C 12 MAY 2000   CJFC    Include block /SNAILS/ for soil nails            common
(022) C 12 MAY 2000   CJFC    Increase size of VALBST from 5164 to 5659        common
(023) C 21 MAY 2000   CJFC    Include soil nail values to be printed in /BEST/ common
(024) C 24 MAY 2000   CJFC    Increase max number of surf points from 41 to 101common
(025) C 24 MAY 2000   CJFC    Increase max number of layers from 20 to 35      common
(026) C 25 MAY 2000   CJFC    Increase max general surf points from 25 to 100  common
(027) C 26 MAY 2000   CJFC    Rename TIME and Date TIME6 and DATE11            common
(028) C 12 JAN 2003   CJFC    Include flag IDBISH for solution type            common
(029) C 29 JAN 2003   CJFC    Include flag IDCOMB(99) for combined analysis    common
(030) C 03 MAR 2003   CJFC    Rename IDBISH to METHOD                          common
(031) C 03 MAR 2003   CJFC    Include MISC(5), VALMSC(5) and IFLAG(10) for any use
(032) C 06 MAR 2003   CJFC    Add SEFF(99) and STOT(99) to common /SURF/       common
(033) C 06 MAR 2003   CJFC    Set size of storage for /SURF/ as Parameter      common
(034) C 18 MAR 2003   CJFC    Include file BEAST.LOG on unit NF18              common
(035) C                                                                   common
```

```
C      PRESENT SIZE LIMITATIONS ARE (SET IN SR/CONTRL) :                 common
C                                                                        common
C     3500 ELEMENTS                                                      common
C     3636 NODAL POINTS                                                  common
C      101 SURFACE NODAL POINTS                                          common
C       50 MATERIALS                                                     common
C      150 MATERIAL TRIANGLES                                            common
C       35 HORIZONTAL LAYERS                                             common
C       25 VERTICAL SECTIONS WITH SU0-VALUES WITH DEPTH                  common
C       25 SU0-VALUES AT EACH VERTICAL SECTION                           common
C       25 VERTICAL SECTIONS WITH PWP-VALUES WITH DEPTH                  common
C       25 PWP-VALUES AT EACH VERTICAL SECTION                           common
C       50 POINT FORCES                                                  common
C       20 STRIPS WITH DISTRIBUTED STRESSES                              common
C       30 GENERAL SHEAR SURFACES                                        common
C      100 POINTS ON EACH GENERAL SURFACE                                common
C       99 NUMBER OF SLICES                                              common
C       75 NUMBER OF SOIL NAILS                                          common
C                                                                        common
       IMPLICIT INTEGER*4(I-N) , REAL*8(A-H,O-Z)                         common
       INTEGER*4 TIME6(6)                                                common
C                                                                        common
C      SET THE SIZE NEEDED FOR STORAGE OF /SURF/ COMMON BLOCK            common
C      NUMVAL = NUMBER OF REALS IN /SURF/ (53*99+610=5857) , SET IN SR/CONTRL
C                                                                        common
       PARAMETER (MAXSRF=5857)                                           common
C                                                                        common
       COMMON /MASTER/ CONFRC,CONLTH,FCTSUC,FCTTAN,IDTYP,IDEFTO,         common
     *                 NUMGEN,NUMSLC,SIDSHR,VALH3(3),VALR(3),RFACT,      common
     *                 IDSPDP,NF5,NF6,NF14,NF15,NF16,NF17,IERR,          common
     *                 PI,SF,NUMSRF,NTYP,JPRINT,IDZSL,CRTFRC,CRTSCR,     common
     *                 SCORE,EPS,SFLIM,SFTZ,SFMIN,SFMAX,E2LIM,IPRTTP,    common
     *                 JPLOT,INNF7,IPRTCM,NF7PST,IPSTCM,SFLOW,E2BIG,     common
     *                 ICMTYP,ITENSP,ITENSE,IDUESA,TIME6,METHOD,         common
     *                 MISC(5),VALMSC(5),IFLAG(10),NF18                  common
C                                                                        common
       COMMON /TEXT/ ITEXT(80,2),MATPLT(100,100),DATE11                  common
       CHARACTER*1 ITEXT,MATPLT                                          common
       CHARACTER*11 DATE11                                               common
C                                                                        common
       COMMON /IGEOMS/ NUMLAY,NUMELX,NUMELZ,NUMEL,NUMNP,                 common
     *                 IJKL(4,3500),MATRL(3500),NUMTRI,MATTRI(150),      common
     *                 LAYMAT(35)                                        common
       COMMON /GEOMSH/ XWALL,HWALL,RWALL,ZWALL,XND(3636),ZND(3636),      common
     *                 XFREE(101),ZFREE(101),ZROCK(101),XTRI(3,150),     common
     *                 ZTRI(3,150),BOTLAY(35),VALND(3636)                common
C                                                                        common
       COMMON /ISOLPR/ NUMMAT,NUMXSU,NODSU,NUMZSU(25)                    common
       COMMON /SOLPRP/ CRACKZ,CRACKW,PHIREF,VALMAT(20,50),XSU(25),       common
     *                 ZSU(25,25),SUXXZZ(25,25),SUNODE(3636)             common
C                                                                        common
       COMMON /IWATER/ IDPWP,NUMXPW,NODPWP,NUMZPW(25)                    common
       COMMON /WATER1/ WATERZ,GAMWAT,GAMPWP,PWPMIN,XPWP(25),ZPWP(25,25), common
     *                 PWPZ(25,25),PWPNOD(3636),GRWLEV(25)               common
C                                                                        common
       COMMON /ILOA/ NUMPNT,NUMSIG                                       common
       COMMON /LOAD/ FCTPNT,FCTSIG,SIGTOP,ACCZRT,ACCXRT,                 common
     *               PNTXZ(2,50),PNTFRC(2,50),STRIPX(2,20),SIGZ(2,20),   common
     *               TAUX(2,20),XTOP1,XTOP2                              common
C                                                                        common
       COMMON /IGENER/ IDGEN,NUMPG(30)                                   common
       COMMON /GENERL/ XGEN(100,30),ZGEN(100,30),                        common
     *                 PWPGEN(100,30),SIGGEN(100,30),TAUGEN(100,30)      common
C                                                                        common
       COMMON /ISUR/ NUMVAL,IDCOMB(99)                                   common
       COMMON /SURF/ XSRF(300),ZSRF(300),XSLC(5,99),ZSLC(5,99),          common
     *               AREA(99),H1(99),H2(99),H3(99),HS(99),U1(99),        common
     *               U2(99),U3(99),E1(99),E2(99),T1(99),T2(99),          common
     *               P(99),S(99),SEFF(99),STOT(99),SS(99),SINB(99),      common
     *               COSB(99),BETA(99),                                  common
     *               WX(99),WZ(99),WM(99),TAN1(99),TAN2(99),TAN3(99),    common
     *               C1(99),C2(99),C3(99),R(99),STORE(10),TANB(99),      common
     *               H20(99),H30(99),R0(99),QZ(99),WORK(99),D34(99),     common
     *               DPAR(99),SU2(99),SU3(99),SNWX(99),SNWZ(99),SNWM(99) common
C                                                                        common
       COMMON /SCRTCH/ BUFF(2000)                                        common
C                                                                        common
       COMMON /IBES/ INTVAL(3),INTSN(225),IDCMBB(99)                     common
       COMMON /BEST/ SFBB,SCBB,RFBB,VALBST(MAXSRF),VALSN(1425)           common
C                                                                        common
       COMMON /ISNAIL/ NNAILS,ISNFLG(75),MODESN(75),INTSLC(75)           common
       COMMON /SNAILS/ SNXHED(75),SNZHED(75),SNXTIP(75),SNZTIP(75),      common
     *                 SNCCY(75),SNDIAM(75),SNTAUT(75),SNTAUC(75),       common
     *                 SNDIST(75),SNAXLY(75),SNLATY(75),SNFHED(75),      common
     *                 SNMISC(3,75),SNLENG(2,75),SNFRC(2,75)             common
```

```
C                                                                     common
C     --------------------                                            common
C     ABOVE VALUES ARE :                                              common
C     --------------------                                            common
C                                                                     common
C /MASTER/  MASTER CONTROL DATA ETC.                                  common
C                                                                     common
C  CONFRC = CONVERTION FACTOR FORCES , NEW=GIVEN*CONFRC               common
C  CONLTH = CONVERTION FACTOR LENGTH , NEW=GIVEN*CONLTH               common
C  FCTSUC = MATERIAL FACTOR UNDR.STRGTH/COHESION :  SUDESIGN=SUCHARACT*FCTSU
C  FCTTAN = MATERIAL FACTOR ON TAN(PHI) : TAN(PHI)DES=TAN(PHI)CHAR*FCTTANcommon
C  IDTYP  = PROBLEM TYPE ID (1=STAB/BEARING 2=EARTH PRESSURE)         common
C  IDEFTO = EFFECTIVE OR TOTAL STRESS ANALYSIS ID (1=EFF 2=TOT 3=COMBINED)
C  NUMGEN = NUMBER OF GIVEN GENERAL SHEAR SURFACES                    common
C  NUMSLC = NUMBER OF SLICES TO BE USED                               common
C  SIDSHR = SIDE SHEAR FACTOR (IN XZ-PLANE)                           common
C  VALH3  = (3) VALUES FOR H3-ASSUMPTION :                            common
C                H3/L3=(VAL1+(VAL2-VAL1)*X/XTOT)                      common
C  VALR   = (3) VALUES FOR R-ASSUMPTION :                             common
C                R    =(VAL1+(VAL2-VAL1)*X/XTOT+VAL3*H/HMAX)*FCTR     common
C  RFACT  = FACTOR ON ABOVE R-VALUES , SET BY SR/RMULT DURING SOLUTION PROCESS
C  IDSPDP = SINGLE/DOUBLE PRECISION PROGRAM VERSION ID (1=SNGL 2=DBL)    common
C  NF5    = UNIT NUMBER , USER'S TERMINAL INPUT  (KEYBOARD)           common
C  NF6    = UNIT NUMBER , USER'S TERMINAL OUTPUT (SCREEN)             common
C  NF14   = UNIT NUMBER , USER'S FORMATTED INPUT FILE WITH COMMENT LINES common
C  NF15   = UNIT NUMBER , FORMATTED INPUT FILE , COMMENT LINES REMOVED   common
C  NF16   = UNIT NUMBER , FORMATTED OUTPUT FILE FOR PRINTING          common
C  NF17   = UNIT NUMBER , FORMATTED OUTPUT FILE FOR POST-PROCESSOR    common
C  NF18   = UNIT NUMBER , FORMATTED OUTPUT FILE WITH RUN-TIME MESSAGES   common
C  IERR   = ERROR CONDITION INDICATOR                                 common
C  PI     = 3.14159......                                             common
C  SF     = GIVEN OR COMPUTED FACTOR OF SAFETY ON DESIGN SOIL STRENGTH   common
C  NUMSRF = SHEAR SURFACE NUMBER                                      common
C  NTYP   = SHEAR SURFACE TYPE ID  (1=GENERAL 2=CIRCLE 3=COMBINED 4=PLANE)
C  JPRINT = PRINT CODE FOR SOLVER AND SLICE ROUTINES                  common
C             0=NONE 1=LIMITED 2=TRACE 3=DETAILED TRACE               common
C  IDZSL  = GIVEN INPUT VALUE FOR 'NUMSLC' (MAY BE ZERO)              common
C  CRTFRC = CONVERGENCE CRITERION FORCES                              common
C  CRTSCR = CONVERGENCE CRITERION SOLUTION SCORE, STOP WHEN SCORE IS LOWER
C  SCORE  = SURFACE SOLUTION QUALITY SCORE , 0.0 = PERFECT            common
C  EPS    = SMALL VALUE (1.0E20)                                      common
C  SFLIM  = MINIMUM SAFETY FACTOR FROM TAN(BETA)*TAN(PHI)             common
C  SFTZ   = SAFETY FACTOR FROM T=0.0 FORCE EQUILIBRIUM SOLUTION       common
C  SFMIN  = MINIMUM ALLOWED SAFETY FACTOR FOR SOLUTION ROUTINES       common
C  SFMAX  = MAXIMUM ALLOWED SAFETY FACTOR                             common
C  E2LIM  = E2-FORCE AT LAST SLICE FOR HIGH S.F.                      common
C  IPRTTP = PRINT TYPE SLICE OUTPUT  (1=FORCES 2=STRESSES)            common
C  JPLOT  = A PLOT WILL BE MADE ON NF6 OF PRESENT PRINTED SURFACE IF NON-ZERO
C  INNF7  = INDICATOR NF7 DATA PRINT LINE PRINTER                     common
C              (0:NO DATA 1:DATA NOT PRINTED 2:DATA PRINTED)          common
C  IPRTCM = INDICATOR FOR PRINT TO LINE PRINTER OF DATA IN /SURF/ (0:NO 1:YES)
C  NF7PST = INDICATOR NF7 DATA PRINT POST PROCESSOR                   common
C              (0:NO DATA 1:DATA NOT PRINTED 2:DATA PRINTED)          common
C  IPSTCM = INDICATOR FOR PRINT TO POST PROCS OF DATA IN /SURF/ (0:NO 1:YES)
C  SFLOW  = LOWEST SAFETY FACTOR, USED TO DECIDE STORING ON NF7       common
C  E2BIG  = HIGHEST EARTH PRESSURE, USED TO DECIDE STORING ON NF7     common
C  ICMTYP = COMBINED SURFACE TYPE (1=CIRCLE CENTER ABOVE  2,3=CENTER BELOW)
C  ITENSP = ALLOW P-FORCE TENSION IN SCORE CALCS (0=NO 1=YES)         common
C  ITENSE = ALLOW E-FORCE TENSION IN SCORE CALCS (0=NO 1=YES)         common
C  IDUESA = INDICATOR FOR UNDRAINED EFFECTIVE STRESS ANALYSIS (0=NO 1=YES)
C  TIME6  = (6) REAL TIME VALUES (YEAR, MONTH, DAY, HOUR, MIN, SEC)      common
C  METHOD = Solutn method -1=Frc.eql 0=Old 1=Bish.simpl 2=Bish.mod 3=Beast-2003
C  MISC   = (5) Miscellaneous integer values read as input.  Present use :
C           (1)=1 Shear surface exit angle modification is allowed       common
C  VALMSC = (5) Miscellaneous real values read as input. Present use : None
C  IFLAG  = (10) Flags set by Beast as needed.  Present use :         common
C           (01)=1 The shear surface was modified due to rock surf interstn
C           (02)=1 The shear surface was modified due to steep exit anglecommon
C           (03)=1 Flag set in SR/SUCRCL, checked by SR/CIRCLE          common
C                                                                     common
C /TEXT/    HEADING TEXT AND CHARACTER DATA                           common
C                                                                     common
C  ITEXT  = (80,2) TWO HEADING LINES                                  common
C  MATPLT = (100,100) AREA USED TO FORM PLOT PICTURE                  common
C  DATE11 = DATE OF PRESENT PROGRAM VERSION (e.g. "26 May 2000")      common
C                                                                     common
C /GEOMSH/  MESH GEOMETRY VALUES                                      common
C                                                                     common
C  NUMELX = NUMBER OF MESH ELEMENTS IN X-DIRECTION                    common
C  NUMELZ = NUMBER OF MESH ELEMENTS IN Z-DIRECTION                    common
C  NUMLAY = NUMBER OF HORIZONTAL SOIL LAYERS                          common
C  NUMEL  = NUMBER OF MESH ELEMENTS = NUMELX*NUMELZ                   common
C  NUMNP  = NUMBER OF MESH NODAL POINTS = (NUMELX+1)*(NUMELZ+1)       common
C  XWALL  = VERTICAL WALL X-POSITION , IF PRESENT                     common
```

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C  HWALL  = VERTICAL WALL HEIGHT , I.E. DISTANCE SOIL SURFACE TO TOE     common
C  RWALL  = VERTICAL WALL ROUGHNESS (-1.0 TO +1.0)                       common
C  ZWALL  = VERTICAL WALL TIP Z-VALUE                                    common
C  XND    = (MAXNP) MESH NODAL POINT X-COORDINATES                       common
C  ZND    = (MAXNP) MESH NODAL POINT Z-COORDINATES                       common
C  XFREE  = (NUMELX+1) SOIL SURFACE NODES X-COORDINATES                  common
C  ZFREE  = (NUMELX+1) SOIL SURFACE NODES Z-COORDINATES                  common
C  ZROCK  = (NUMELX+1) ROCK SURFACE Z-COORDINATES (X AS FOR SOIL SURF)   common
C                                                      I J   1 2         common
C  IJKL   = (4,MAXEL) 4 NODAL POINTS AT ELEMENT CORNERS:       =         common
C  MATRL  = (MAXEL) MATERIAL ID FOR EACH ELEMENT          L K   4 3      common
C  NUMTRI = NUMBER OF TRIANGLES WITH GIVEN MATERIAL I.D.                 common
C  MATTRI = (150) TRIANGLE MATERIAL I.D.                                 common
C  XTRI   = (3,150) MATERIAL TRIANGLES CORNER X-COORDINATES              common
C  ZTRI   = (3,150) MATERIAL TRIANGLES CORNER Z-COORDINATES              common
C  BOTLAY = (35) Z-VALUE AT LAYER BOTTOM                                 common
C  LAYMAT = (35) SOIL LAYER MATERIAL TYPE I.D.                           common
C  VALND  = (3636) VALUES (PWP OR SU) AT MESH NODES TO BE PLOTTED        common
C                                                                        common
C /SOLPRP/  SOIL PROPERTY VALUES                                         common
C                                                                        common
C  NUMMAT = NUMBER OF MATERIALS                                          common
C  NUMXSU = NUMBER OF VERTICAL X-LINES WHERE SU0-VALUES ARE GIVEN        common
C  NODSU  = NUMBER OF NODES WHERE SU0-VALUES ARE GIVEN                   common
C  CRACKZ = CRACK DEPTH BELOW SOIL SURFACE ON ACTIVE SIDE                common
C  CRACKW = CRACK WATER DEPTH , I.E. DISTANCE CRACK BOTTOM TO WATER SURFACE
C  PHIREF = FRICTION ANGLE REFERENCE PRESSURE, SEE FORMULA BELOW         common
C  VALMAT = (20,50) MATERIAL PROPERTIES :                                common
C           01 =   TOTAL UNIT WEIGHT (F/L**3)                            common
C           02 =   COHESION IN EFFECTIVE STRESS ANALYSIS (F/L**2)        common
C           03 =   TAN(PHI) EFFECTIVE ANGLE OF INTERNAL FRICTION AT 'PHIREF'
C           04 =   PHIRED : PHI(SIG)=PHIANG-PHIRED*LOG10(SIG/PHIREF) (DEGR)
C           05 =   EXCESS PORE-WATER PRESSURE FOR PRESENT MATERIAL  (F/L**2)
C           06 =   RU-FACTOR FOR MATERIAL : PWP=RU*GAMTOT*Z              common
C           07 =   B-FACT FOR UNDRAINED PWP COMPUTATION : PWP=B*(SIGA-D*SIGD)
C           08 =   K-NOT  : INITIAL EFFECTIVE STRESS RATIO  SIG30/SIG10  common
C           09 =   B-SIG2 : INTERMEDIATE PRINCIPAL STRESS  B=(S2-S3)/(S1-S3)
C           10 =   D-PARAMETER IN 7 ABOVE = VALMAT(10,N)*SU(BETA)        common
C           11 =   SU-ACTIVE/SU0                                         common
C           12 =   SU-DIRECT/SU0                                         common
C           13 =   SU-PASSIVE/SU0                                        common
C           14 =   SU0 ASSIGNED TO EACH MATERIAL  (F/L**2)               common
C           15 =   ISOTROPIC SU INDICATOR (0.0=NO 1.0=YES)               common
C           16 -20 NOT USED                                              common
C  XSU    = (25) X-COORDS FOR VERTICAL LINES WITH GIVEN SU0 POINTS WITH DEPTH
C  NUMZSU = (25) NUMBER OF SU0 POINTS WITH DEPTH ON EACH VERTICAL LINE   common
C  ZSU    = (25,25) Z-COORDS FOR POINTS WITH GIVEN SU0 VALUES  (Z,X)     common
C  SUXXZZ = (25,25) GIVEN SU0 VALUES AT X-LINES AND WITH DEPTH (Z,X)     common
C  SUNODE = (MAXNP) UNDRAINED STRENGTH VALUES SU0 AT NODES               common
C                                                                        common
C /WATER1/  FREE WATER AND PORE-WATER-PRESSURE (PWP) INFORMATION         common
C                                                                        common
C  IDPWP  = PWP CONDITION I.D. (1=HYDROSTATIC 2=NON-HYDROSTATIC)         common
C  NUMXPW = NUMBER OF VERTICAL X-LINES WITH GIVEN PWP VALUES WITH DEPTH  common
C  NODPWP = NUMBER OF NODES WITH GIVEN PWP                               common
C  WATERZ = FREE HORIZONTAL WATER TABLE Z-LEVEL                          common
C  GAMWAT = FREE WATER UNIT WEIGHT (FOR WATER LOADS ON SOIL SURFACE)     common
C  GAMPWP = UNIT WEIGHT OF PORE WATER (=GAMWAT IF HYDROSTATIC CONDTNS)   common
C  PWPMIN = MINIMUM ALLOWED PWP  (CAPILLARY TENSION)                     common
C  XPWP   = (25) X-COORDINATES FOR SVERTICAL LINES WITH GIVEN PWP WITH DEPTH
C  NUMZPW = (25) NUMBER OF PWP POINTS WITH DEPTH ON EACH VERTICAL LINE   common
C  ZPWP   = (25,25) Z-COORDS FOR POINTS WITH GIVEN PWP VALUES  (Z,X)     common
C  PWPZ   = (25,25) GIVEN PWP VALUES AT X-LINES AND WITH DEPTH  (Z,X)    common
C  PWPNOD = (MAXNP) PWP GIVEN AT EACH INDIVIDUAL NODE                    common
C  GRWLEV = (25) GROUND WATER Z-LEVELS BASED UPON PWP X-LINES INPUT      common
C                                                                        common
C /LOAD/    LOAD DATA VALUES                                             common
C                                                                        common
C  NUMPNT = NUMBER OF GIVEN POINT FORCES (FORCE/UNIT LENGTH IN Y-DIRECTION)
C  NUMSIG = NUMBER OF GIVEN SURFACE STRIP LOAD AREAS (STRESS)            common
C  FCTPNT = LOAD FACTOR ON GIVEN POINT FORCES                            common
C  FCTSIG = LOAD FACTOR ON GIVEN SURFACE STRIP LOADING                   common
C  SIGTOP = UNIFORM INITIAL VERTICAL STRESS ACTING AT SOIL SURFACE       common
C  ACCZRT = Z-DIRECTION ACCELLERATION RATIO (1.0=NORMAL 0.0=NO WEIGHT)   common
C  ACCXRT = X-DIRECTION ACCELLERATION RATIO (0.0=NORMAL 1.0=1G HORIZONTALLY)
C  PNTXZ  = (2,50) POINT FORCES X- AND Z-COORDINATES (1=X 2=Z)           common
C  PNTFRC = (2,50) POINT FORCES X- AND Z-VALUES (1=X 2=Z) FORCE/LENGTH   common
C  STRIPX = (2,20) STRIP LOAD X-VALUES (1=START-X 2=END-X)               common
C  SIGZ   = (2,20) STRIP LOAD Z-DIRECTION NORMAL STRESS (1=START 2=END)  common
C  TAUX   = (2,20) STRIP LOAD X-DIRECTION SHEAR STRESS  (1=START 2=END)  common
C  XTOP1  = STRESS 'SIGTOP' ACTS BETWEEN XTOP1 AND XTOP2 ONLY            common
C  XTOP2  = STRESS 'SIGTOP' ACTS BETWEEN XTOP1 AND XTOP2 ONLY            common
C                                                                        common
```

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C /GENERL/  GIVEN GENERAL SHEAR SURFACE VALUES                          common
C                                                                       common
C  IDGEN  = PRESENT GENERAL SHEAR SURFACE NUMBER                        common
C  NUMPG  = (30) NUMBER OF POINTS ON EACH GENERAL SHEAR SURFACE         common
C  XGEN   = (100,30) GENERAL SHEAR SURFACE POINTS X-COORDINATES         common
C  ZGEN   = (100,30) GENERAL SHEAR SURFACE POINTS Z-COORDINATES         common
C  PWPGEN = (100,30) GENERAL SHEAR SURFACE POINTS PORE-WATER-PRESSURES   common
C  SIGGEN = (100,30) INITIAL NORMAL STRESS ALONG GENERAL SURFACE        common
C  TAUGEN = (100,30) INITIAL SHEAR STRESS ALONG GENERAL SURFACE         common
C                                                                       common
C /SURF/    SHEAR SURFACE VALUES                                        common
C                                                                       common
C  NUMVAL = NUMBER OF REALS IN /SURF/ (53*99+610=5857) , SET IN SR/CONTRLcommon
C  IDCOMB = (99) Flags governing case in combined analysis, 1=Eff 2=Tot  common
C  XSRF   = (300) PRESENT SHEAR SURFACE X-VALUES                        common
C  ZSRF   = (300) PRESENT SHEAR SURFACE Z-VALUES                        common
C  XSLC   = (5,99) SLICE CORNER (1-4) AND CENTER (5) X-VALUES           common
C  ZSLC   = (5,99) SLICE CORNER (1-4) AND CENTER (5) Z-VALUES           common
C  AREA   = (99) SLICE AREA                                             common
C  H1     = (99) HEIGHT OF HORIZONTAL FORCE 'E1' ABOVE SHEAR SURFACE    common
C  H2     = (99) HEIGHT OF HORIZONTAL FORCE 'E2' ABOVE SHEAR SURFACE    common
C  H3     = (99) DISTANCE FROM CORNER-3 TO SHEAR SURFACE NORMAL FORCE 'P'common
C  HS     = (99) DISTANCE FROM SHEAR SURFACE TO SIDE SHEAR FORCE        common
C  U1     = (99) PORE-WATER PRESSURE FORCE ON FACE-1                    common
C  U2     = (99) PORE-WATER PRESSURE FORCE ON FACE-2                    common
C  U3     = (99) PORE-WATER PRESSURE FORCE ON FACE-3                    common
C  E1     = (99) HORIZONTAL FORCE ON FACE-1 , EFFECTIVE                 common
C  E2     = (99) HORIZONTAL FORCE ON FACE-2 , EFFECTIVE                 common
C  T1     = (99) VERTICAL SHEAR FORCE ON FACE-1                         common
C  T2     = (99) VERTICAL SHEAR FORCE ON FACE-2                         common
C  P      = (99) NORMAL FORCE AT SHEAR SURFACE , EFFECTIVE              common
C  S      = (99) SHEAR FORCE AT SHEAR SURFACE                           common
C  SEFF   = (99) S-FORCE BY EFFECTIVE STRESSES, COMBINED ANALYSIS       common
C  STOT   = (99) S-FORCE BY TOTAL STRESSES, COMBINED ANALYSIS           common
C  SS     = (99) SIDE SHEAR FORCE CALCULATED WITH SF = 1.0              common
C  SINB   = (99) SINE(BETA) , BETA IS SHEAR SURFACE INCLINATION         common
C  COSB   = (99) COSINE(BETA) , BETA IS SHEAR SURFACE INCLINATION       common
C  BETA   = (99) SHEAR SURFACE INCLINATION , RADIANS                    common
C  WX     = (99) BODY FORCES IN X-DIRECTION , PWP INCLUDED              common
C  WZ     = (99) BODY FORCES IN Z-DIRECTION , PWP AND QZ INCLUDED       common
C  WM     = (99) BODY FORCE MOMENTS W.R.T. SLICE CENTER POINT (5)       common
C  TAN1   = (99) TAN(PHI) AT FACE-1                                     common
C  TAN2   = (99) TAN(PHI) AT FACE-2                                     common
C  TAN3   = (99) TAN(PHI) AT FACE-3 (=SHEAR SURFACE)                    common
C  C1     = (99) UNDRAINED STRENGTH OR COHESION ON FACE-1               common
C  C2     = (99) UNDRAINED STRENGTH OR COHESION ON FACE-2               common
C  C3     = (99) UNDRAINED STRENGTH OR COHESION ON FACE-3 (=SHEAR SURFACE)
C  R      = (99) INTERSLICE ROUGHNESS , T2=R(C*H+E2*TAN2)               common
C  STORE  = (10) SHEAR SURFACE KEY GEOMETRY DATA FOR PRINT              common
C  TANB   = (99) SIN(BETA)/COS(BETA) , BETA IS SLICE BOTTOM INCL.       common
C  H20    = (99) INITIALLY COMPUTED VALUES OF H2                        common
C  H30    = (99) INITIALLY COMPUTED VALUES OF H3                        common
C  R0     = (99) INITIALLY COMPUTED VALUES OF R                         common
C  QZ     = (99) EXTERNAL LOADING IN Z DIRECTION                        common
C  WORK   = (99) SCRATCH STORAGE OF SLICE VALUES                        common
C  D34    = (99) SHEAR SURFACE LENGTH FOR EACH SLICE                    common
C  DPAR   = (99) PWP D-PARAMETER CALCULATED FOR EACH SLICE              common
C  SU2    = (99) UNDRAINED STRENGTH AT FACE 2                           common
C  SU3    = (99) UNDRAINED STRENGTH AT FACE 3 (SHEAR SURFACE)           common
C  SNWX   = (99) BODY FORCE IN X FROM SOIL NAILS, SF = 1.0              common
C  SNWZ   = (99) BODY FORCE IN Z FROM SOIL NAILS, SF = 1.0              common
C  SNWX   = (99) BODY FORCE MOMENT FROM SOIL NAILS, SF = 1.0            common
C                                                                       common
C /SCRTCH/    SCRATCH STORAGE                                           common
C                                                                       common
C  BUFF   = STORAGE TO BE USED BY ANY SUBROUTINE                        common
C                                                                       common
C /BEST/  STORAGE OF VALUES FROM BEST SHEAR SURFACE                     common
C                                                                       common
C  INTVAL = (3)  1:NUMSRF  2:NTYP  3:NUMSLC   (SEE ABOVE)               common
C  INTSN  = (225) SOIL NAIL INTEGER VALUES                              common
C  IDCMBB = (99) Flag IDCOMB saved for the best surface                 common
C  SFBB   = BEST SAFETY FACTOR                                          common
C  SCBB   = SCORE FOR SOLUTION WITH BEST SAFETY FACTOR                  common
C  RFBB   = R-FACTOR FOR SOLUTION WITH BEST SAFETY FACTOR               common
C  VALBST = (5857) IDENTICAL TO COMMON /SURF/ , 'NUMVAL' NOT INCLUDED   common
C  VALSN  = (1425) IDENTICAL TO COMMON /SNAILS/                         common
C                                                                       common
```

```
C /SNAILS/  VALUES RELATED TO SOIL NAILS                                common
C                                                                       common
C  NNAILS = NUMBER OF SOIL NAILS                                        common
C  ISNFLG = (75) FLAG FOR NAIL/SHR.SURF INTERSCTN, 0=No 1=Comp 2=Tens   common
C  MODESN = (75) FAILURE MODE, 1=EXT/TNS 2=EXT/CMP 3=INT/TNS 4=INT/CMP 5=YLD
C  INTSLC = (75) SLICE NUMBER WHERE THE NAIL INTERSECTS THE SHEAR SURFACEcommon
C  SNXHED = (75) SOIL NAIL HEAD X-COORDIONATE                           common
C  SNZHED = (75) SOIL NAIL HEAD Z-COORDIONATE                           common
C  SNXTIP = (75) SOIL NAIL TIP X-COORDIONATE                            common
C  SNZTIP = (75) SOIL NAIL TIP Z-COORDIONATE                            common
C  SNCCY  = (75) SOIL NAIL C/C DISTANCE IN Y-DIRECTION                  common
C  SNDIAM = (75) SOIL NAIL DIAMETER FOR SOIL SKIN FRICTION              common
C  SNTAUT = (75) SOIL NAIL MAXIMUM UNIT SKIN FRICTION, TENSION          common
C  SNTAUC = (75) SOIL NAIL MAXIMUM UNIT SKIN FRICTION, COMPRESSION      common
C  SNDIST = (75) SOIL NAIL DISTANCE FROM HEAD TO START TAU.SKIN         common
C  SNAXLY = (75) SOIL NAIL STRUCTURAL AXIAL YIELD STRENGTH (FORCE)      common
C  SNLATY = (75) SOIL NAIL STRUCTURAL LATERAL YIELD STRENGTH (FORCE)    common
C  SNFHED = (75) SOIL NAIL HEAD PLATE AXIAL CAPACITY (FORCE)            common
C  SNMISC = (3,75) SOIL NAIL MISCELLANEOUS VALUES,                      common
C                  SNMISC(1,i) = -1 flags that nail "i" is de-activated common
C                  The other two values are presently not used.         common
C  SNLENG = (2,75) SOIL NAIL LENGTHS, 1=TOTAL 2=ACTIVE                  common
C  SNFRC  = (2,75) SOIL NAIL FORCES, 1=AXIAL (+=TENS,-=COMP) 2=LATERAL  common
C                                                                       common
C  END OF COMMON                                                        common
```

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Appendix A

Program Beast General Description

COMPUTER PROGRAM BEAST GENERAL DESCRIPTION

INTRODUCTION

BEAST is a limit equilibrium analysis program based upon a general method of slices. It may be used to solve three classes of problems :

* Bearing capacity, i.e. find the factor of safety required for equilibrium.
* Slope stability, i.e. find the factor of safety required for equilibrium.
* Earth pressures, i.e. find the horizontal and vertical force required at the end of a system of slices with given factor of safety.

In each case a potential shear surface is defined, and the degree of soil strength mobilisation along this surface is assumed to be constant.

THEORETICAL BASIS

BEAST can analyse both total stress and effective stress problems, as well as a combination of the two. In the case of effective stresses, the pore water pressures within the soil volume are either assumed known at the start of the analysis, or they are calculated as a part of the solution by an iterative procedure.

Five different solution methods may be used. These methods include force equilibrium with given interslice roughness, Bishop's simplified method and more advanced methods, similar to the Spencer and Morgenstern & Price methods, that satisfy all equilibrium conditions.

BEAST automatically checks the quality of the solutions obtained w.r.t. computed forces and their position. A score that reflects the quality is given to each solution, this score may then be used to determine the set of assumptions that gives the best solution quality.

SOIL PROPERTIES

For *effective stress* analysis the required soil properties are :

Unit weight, angle of internal friction and cohesion. The user may specify that the friction angle shall depend upon the effective normal stresses. The user may also give pore water pressure parameters to be used for an undrained effective stress analysis, (UESA).

For *total stress* analysis the required soil properties are :

Unit weight and three undrained shear strength values corresponding to active, direct simple shear and passive tests (ADP).

PORE WATER PRESSURES

The user has several different options that may be used to generate any variation of pore water pressures within the soil body. These pressures are either known at the start of the analysis, or they are calculated in the case of an UESA type solution.

GEOMETRY

BEAST assumes plane strain geometry with a user defined side shear force to account for 3D effects. The user specifies the position of a free soil surface and a rock surface in a X- and Z-coordinate system. Shear surfaces that intersect the rock surface are automatically modified to follow the rock surface.

Any variation of soil properties through the soil volume can be specified by the use of a finite element type mesh, horizontal layers and user defined material triangles.

LOADING

The system may be subjected to a wide range of possible loading types : Self weight vertically and laterally (earthquake loads), outside water pressures, seepage forces, given surface distributed loading and given line loads. In addition, BEAST may include the stabilising effects from piles and/or soil nails.

SHEAR SURFACES

BEAST can handle shear surfaces of any shape. General shear surfaces may be specified by the user, and later modified in a search for the critical surface. BEAST has an automatic search facility for circular shear surfaces, and for different types of combined shear surfaces consisting of circles and lines.

COMPUTED RESULTS

For given shear surfaces BEAST may print solutions that include :

* Factor of safety or earth pressure
* Score, a measure of solution quality
* Summary of shear surface geometry
* Forces and stresses at each individual slice
* Degree of shear strength mobilisation between neighbour slices
* Position of the line of thrust and of the normal forces acting against the shear surface.

In addition, input values and computed values along the shear surface may be plotted on a line printer for checking purposes.

Details of geometry, soil parameters and computed results for selected shear surfaces may be stored on a file for use by a post processor program.

Further information about the Beast program can be obtained from :

Carl J. Frimann Clausen
Cidex 424 bis
F - 06330 Roquefort les Pins
France

Telephone (+33) (0)4 9377 5275
Telefax (+33) (0)4 9377 1979
E-mail cjfc@gf-net.com

Appendix B

Undrained Effective Stress Analysis

INTRODUCTION

The reader is referred to Svanø (1981) and to Svanø and Nordal (1988) for a description of the concept of an undrained effective stress analysis.

The practical application of the method in BEAST is slightly different from the approach given in the above papers, as BEAST works in terms of known (assumed) pore water pressures. However, the basic theory used is the same.

EFFECTIVE STRESSES

Figure B.1 shows the effective stress Mohr Circles for a soil element with the notation that is used below (and within BEAST). Two states of stress are shown : (1) the initial conditions prior to the undrained stress change, and (2) the new effective stresses after the element has been subjected to some change in total stresses.

The initial pore water pressure can be regarded as a back pressure and taken as zero.

The following equations follow directly from an inspection of Figure B.1 :

ATT =	C/tan(PHI)	(B.1)
SIGN =	P/D34	(B.2)
TAU =	S/D34	(B.3)
ADIST =	SQRT((SIGN+ATT)**2 + TAU**2)	(B.4)
RAD =	ADIST * tan(PHI) / SF	(B.5)
SIGAVR =	SQRT(RAD**2 + ADIST**2) - ATT	(B.6)
SIG1 =	SIGAVR + RAD	(B.7)
SIG3 =	SIGAVR - RAD	(B.8)
SIG2 =	SIG3 + B2 * (SIG1 - SIG3)	(B.9)

where SIG2 is the intermediate principal stress. The changes in effective stresses are then given by :

DSIG1 =	SIG1 - SIG10	(B.10)
DSIG3 =	SIG3 - SIG30	(B.11)
DSIG2 =	DSIG3 + B2 * (DSIG1 - DSIG3)	(B.12)

PORE WATER PRESSURES

It is assumed that the PWP equation proposed by Janbu (1979) applies :

DPWP =	B * (DSIGAVR - D * DSIGDEV)	(B.13)

where

DPWP = Change in pore water pressure
B = PWP parameter, 1.0 for saturated soil
DSIGAVR = Change in average total stress
D = PWP parameter, 0.0 for an elastic material
DSIGDEV = Change in deviator stress

Since the initial PWP values may be taken as zero, DPWP is equal to PWP and we have :

DSIGAVR = (DSIG1+DSIG2+DSIG3)/3 + PWP (B.14)

DSIGDEV = ABS(DSIG1-DSIG3) (B.15)

BEAST PROCEDURES

The above equations are satisfied through an iterative solution process :

1. Assume at set of PWP values, BEAST makes the following initial assumption :

   PWP = 0.33 * WZ / D34 (B.16)

2. Solve the system and find SF and all slice forces.

3. Calculate new effective stresses and effective stress changes from equations (B.1) to (B.12).

4. Calculate changes in total stresses and in deviator stress from (B.14) and (B.15). For the total stress changes, use the assumed PWP values.

5. Calculate the PWP values given by equation (B.13).

6. Take next PWP assumption as the average of the assumed and the calculated values, and repeat from point 2 above.

The convergence criterion used by BEAST is that the sum of PWP times D34 taken over all slices shall be within 2 percent from one iteration to the next. For most cases it is found that 4-6 iterations are required.

MODELLING OF THE D-FACTOR

The results of the above analysis will depend upon the D-factor that relates changes in deviator stress to changes in pore water pressure.

For an ideal elastic material the D-parameter will be zero. For real soils, however, its value must be expected to depend upon a number of factors :

* Type of material, e.g. normally consolidated or over-consolidated.
* Relative density for sands.
* Degree of ultimate strength mobilisation.
* Direction of stress changes as compared to the initial stresses, i.e. active or passive conditions.

It follows that the D-factor should be determined from representative laboratory tests with pore water pressure measurements.

In order to give the user maximum freedom to model the D-parameter, BEAST interprets the Su0 and SuA/Su0 etc. values given for total stress analysis as D-parameters if UESA was specified.

For each material a value D-FCT is given as part of the input data. The actual D-parameter used in the analysis is calculated as :

D = Su(BETA) * D-FCT (B.17)

This allows the D-parameter to vary from point to point, and also to depend upon the inclination of the shear surface.

REFERENCES

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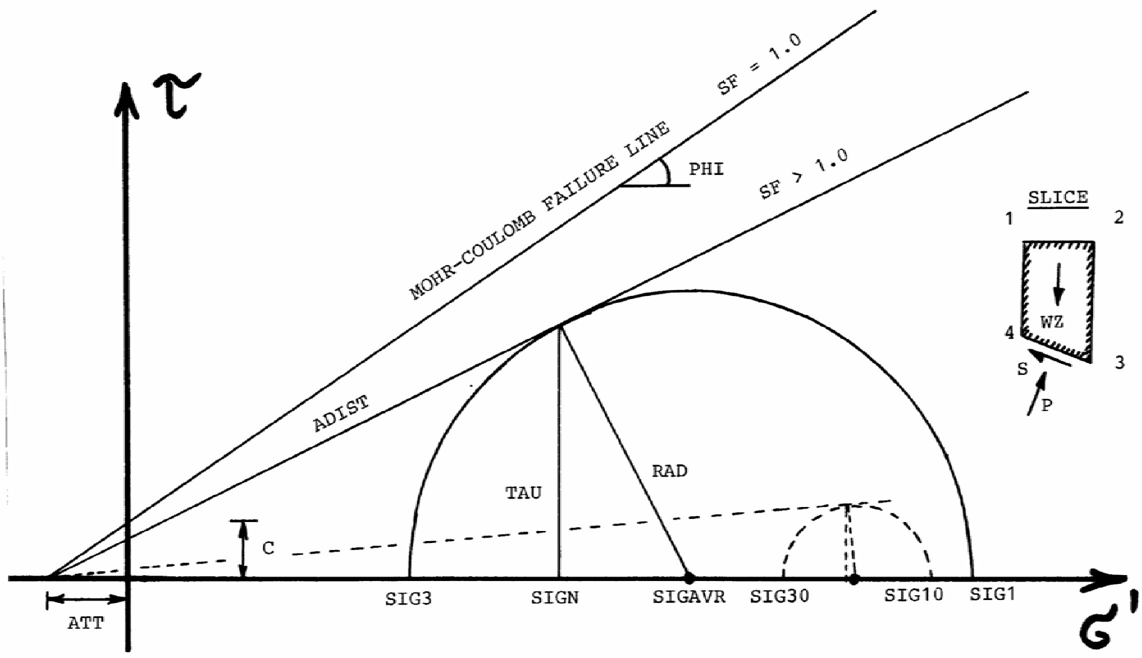


Figure B.1

Effective stress state notation used

Appendix C

Example Cases Analysed by Beast

1 Strip loading on clay
2 Strip loading on weightless sand
3 Strip loading on sand with self weight
4 Offshore platform on clay
5 Simple clay slope, s_u analysis
6 Simple clay slope, effective stress analysis
7 The Lodalen slide
8 Rockfill dam with central tilting core
9 Active and passive earth pressures against a wall
10 Undrained effective stress analysis, strip footing
11 Clay slope, combined analysis
12 Slope with soil nails
13 Slopes analysed by different authors

TEST EXAMPLE : 1

Strip Loading on Clay with Constant Shear Strength

The case analysed is shown on the figure below. Input data file NF14 is included at the end of this section.

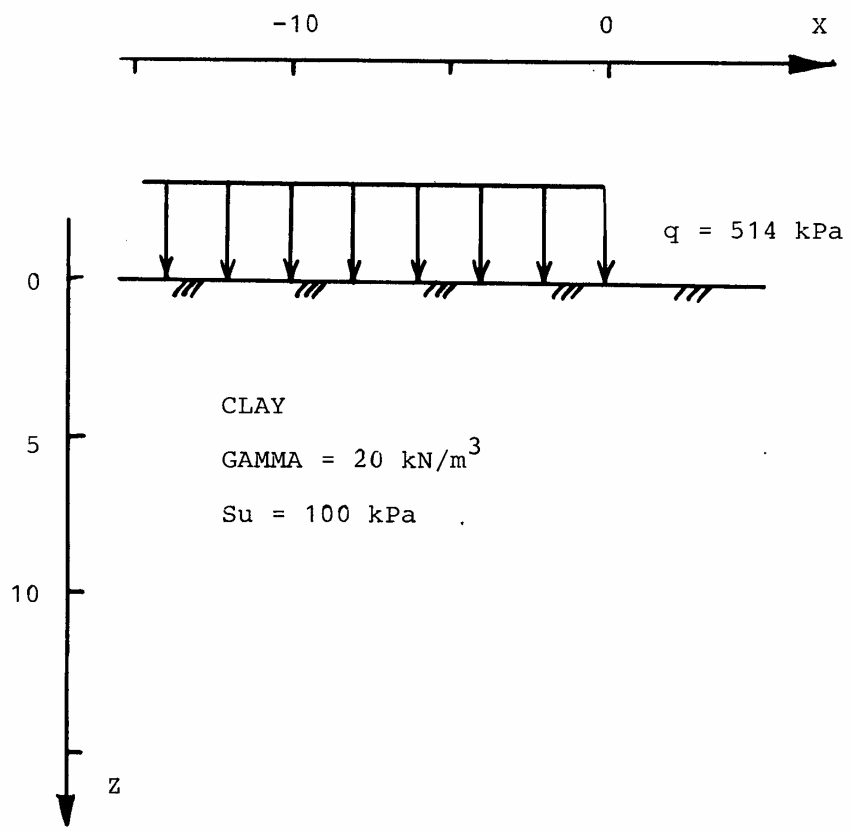


Figure C.1.1 : Test Example 1, Strip Loading on Clay

Test Example 1 Results

POSITION OF CRITICAL SHEAR SURFACE

With input data as shown in the input file, the general shear surface (which is the theoretical Prandtl failure surface) was "stretched" as shown below, and the safety factor and the score calculated. Control parameters used were :

IDEFTO	NUMSLC	H3	ROUGHNESS R1 R2 R3
32	25	0 0	0 0 1

XFACT	ZFACT	SF	SCORE	R-FACTOR
0.80	0.80	1.109	0.000	0.70
0.90	0.90	1.008	0.000	0.50
0.95	0.95	0.982	0.000	0.40
1.00	1.00	0.978	0.000	0.40
1.05	1.05	0.981	0.000	0.40
1.10	1.10	0.993	0.000	0.40
1.20	1.20	1.025	0.000	0.50

The theoretical surface (stretching factor = 1.0) gives the lowest safety factor, and the SF values are close to the theoretical solution of 1.00.

INFLUENCE OF INTER-SLICE ROUGHNESS ASSUMPTION

The critical surface was re-analysed with a number of different values for the initial interslice roughness assumption, given by the parameters R1, R2 and R3 in the below table (see Section 4.2) :

R1	R2	R3	SF	SCORE	R-FACTOR
0	0	0	0.943	0.000	0.00
1	0	0	0.947	0.000	0.40
0	1	0	0.957	0.000	1.00
0	0	1	0.978	0.000	0.40
1	1	0	0.959	0.000	1.00
0	1	1	1.015	0.000	0.70
1	0	1	0.963	0.000	0.20
1	1	1	1.004	0.000	0.60

The detailed trace output for the case with R = 0 0 1 is shown below.

LOOP1	R.FACTOR	SF.MOM	A	B	SF.ALL	SCORE
1	0.00	0.941	0.937	0.165	0.943	0.000
2	0.10	0.947	0.967	0.085	0.952	0.000
3	0.20	0.953	0.997	0.009	0.961	0.000
4	0.30	0.959	1.025	-0.064	0.970	0.000
5	0.40	0.965	1.054	-0.133	0.978	0.000
6	0.50	0.971	1.081	-0.201	0.987	0.001
7	0.60	0.977	1.109	-0.265	0.996	0.001
8	0.70	0.983	1.136	-0.328	1.004	0.002
9	0.80	0.989	1.163	-0.389	1.012	0.003
10	0.90	0.995	1.190	-0.447	1.021	0.003
11	1.00	1.001	1.216	-0.505	1.029	0.004

where R.FACTOR is the factor on the R-values given as input (i.e. 0-0-1), SF.MOM is the calculated safety factor by the Bishop simplified method, A and B are the scaling factors on the P-forces, and SF.ALL is the final safety factor that satisfies all equilibrium requirements.

BEAST selects the zero-score solution with the highest safety factor. i.e. SF = 0.978. For problems of this type, where zero score solutions have been obtained, it therefore seems that BEAST will give results that are within 5 % of the correct value, and that the calculated safety factor will tend to be on the low side.

Test Example 1 Input/Output Files

```
BEAST TEST EXAMPLE 1 : STRIP LOADING ON CLAY (NC-FACTOR)    17 APR 2003
SMOOTH FOOTING / CONSTANT AND ISOTROPIC CLAY STRENGTH
*
* Date         Sign   Log of file modifications
* -----------  ----   ----------------------------------------------------
* 12 Oct 1993  cjfc   Original version, units used are : kN & m
* 17 Apr 2003  cjfc   Modifications for BEAST rev. 4
*

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1      IDTYP      SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   32      IDEFTO     ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
    1      NUMGEN     NUMBER OF GENERAL SHEAR SURFACES
   25      NUMSLC     NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0      SIDSHR     SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.00 0.00            VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.00 0.00 1.00       VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0      ITENSP     ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0      ITENSE     ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    2      JPRINT     TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -2      IPRTTP     FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    1      JPLOT      CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000    CRTFRC     CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  0.000    CRTSCR     CONVERGENCE CRITERION , SOLUTION SCORE
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
    0      NUMXLN     NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    0      NUMELZ     NUMBER OF ELEMENTS IN Z-DIRECTION
    0      NUMLAY     NUMBER OF HORIZONTAL LAYERS
    0      NUMTRI     NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
  TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
  0 0 0    XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

 ****************** MATERIAL PROPERTIES SECTION
    1      NUMMAT     NUMBER OF DIFFERENT MATERIALS
    0      NUMXSU     NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
    0      NODSU      NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
  0.0      CRACKZ     SURFACE OPEN CRACK DEPTH
  0.0      CRACKW     WATER DEPTH IN OPEN SURFACE CRACK
  0.0      PHIREF     FRICTION ANGLE REFERENCE PRESSURE
 EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
  1     0       0      0       0       0       0       0     0     0      0
 TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
  1     20      1.00    1.00    1.00     100
 X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
 NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)

 ****************** PORE-WATER-PRESSURES SECTION
    1      IDPWP      PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
    0      NUMXPW     NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
    0      NODPWP     NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
   0.0     FCTNOD     FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
    0      WATERZ     HORIZONTAL WATER TABLE Z-LEVEL
   0.0     GAMWAT     FREE WATER UNIT WEIGHT
   0.0     GAMPWP     PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
    0      PWPMIN     MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
  NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)

 ****************** LOAD SECTION
    0      NUMPNT               NUMBER OF POINT (I.E. LINE) LOADS
    1      NUMSIG               NUMBER OF SURFACE DISTRIBUTED LOADS
   0.0     SIGTOP               UNIFORM INITIAL VERTICAL STRESS AT SURFACE
```

```
75----   0.0 0.0 XTOP1,XTOP2         STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
76----   1.0 1.0 FCTPNT,FCTSIG       POINT AND DISTRIBUTED LOAD FACTORS
77----   0.0 1.0 ACCXRT,ACCZRT       ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
78----   POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
79----   STRIP     X1        X2      SIGZ1     SIGZ2     TAUX1     TAUX2
80----     1     -100       0.0       514       514        0         0
81----
82----  **************** GIVEN SHEAR SURFACE
83----    1   11          SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
84----   -10  -8  -6  -4    -2     0     2     4    6  8  10  X-COORD
85----    0    2   4  5.83  6.78  7.07  6.78  5.83  4  2  0   Z-COORD
86----
87---- End of BEAST input file  c:\cjfc\beast\test\data\testx01.002


# BEAST  Output   Program Version = 16 Apr 2003    Time = 17 APR 2003  09:25:46

 BEAST TEST EXAMPLE 1 : STRIP LOADING ON CLAY (NC-FACTOR)    17 APR 2003
 SMOOTH FOOTING / CONSTANT AND ISOTROPIC CLAY STRENGTH

 =====================================================  SAFETY FACTOR =   0.978
 SURFACE NO :   1     SUMMARY OF GEOMETRY AND STRESSES
 =====================================================  SOLUTION SCORE=   0.000

 SURFACE TYPE = GENERAL        X-START   Z-START    X-END    Z-END
                               -10.000    0.000    10.000    0.000

 SOLUTION METHOD = BEAST-2003 / TOTAL STRESS ANALYSIS

 SLICE    X1       Z1       Z2      WXT-FRC     P-STR      E2-STR     U2-STR    ROUGH   H2/Z23
          X2       Z4       Z3      WZT-FRC     S-STR      T2-STR     U3-STR            H3/L34

   1   -10.00    0.00     0.00    0.000E+00  4.347E+02  3.322E+02  0.000E+00 -0.146  0.519
   1    -9.20    0.00     0.80    4.172E+02  1.022E+02 -1.490E+01  0.000E+00         0.497

   2    -9.20    0.00     0.00    0.000E+00  4.394E+02  3.347E+02  0.000E+00 -0.090  0.515
   2    -8.40    0.80     1.60    4.304E+02  1.022E+02 -9.231E+00  0.000E+00         0.498

   3    -8.40    0.00     0.00    0.000E+00  4.439E+02  3.370E+02  0.000E+00 -0.035  0.509
   3    -7.60    1.60     2.40    4.432E+02  1.022E+02 -3.528E+00  0.000E+00         0.498

   4    -7.60    0.00     0.00    0.000E+00  4.484E+02  3.393E+02  0.000E+00  0.022  0.502
   4    -6.80    2.40     3.20    4.560E+02  1.022E+02  2.200E+00  0.000E+00         0.498

   5    -6.80    0.00     0.00    0.000E+00  4.528E+02  3.416E+02  0.000E+00  0.078  0.496
   5    -6.00    3.20     4.00    4.688E+02  1.022E+02  7.952E+00  0.000E+00         0.498

   6    -6.00    0.00     0.00    0.000E+00  4.704E+02  3.442E+02  0.000E+00  0.128  0.489
   6    -5.20    4.00     4.73    4.811E+02  1.022E+02  1.304E+01  0.000E+00         0.498

   7    -5.20    0.00     0.00    0.000E+00  4.748E+02  3.468E+02  0.000E+00  0.179  0.482
   7    -4.40    4.73     5.46    4.928E+02  1.022E+02  1.827E+01  0.000E+00         0.498

   8    -4.40    0.00     0.00    0.000E+00  5.166E+02  3.489E+02  0.000E+00  0.216  0.475
   8    -3.60    5.46     6.02    5.031E+02  1.022E+02  2.206E+01  0.000E+00         0.499


   9    -3.60    0.00     0.00    0.000E+00  5.587E+02  3.486E+02  0.000E+00  0.241  0.471
   9    -2.80    6.02     6.40    5.106E+02  1.022E+02  2.463E+01  0.000E+00         0.499

  10    -2.80    0.00     0.00    0.000E+00  5.612E+02  3.484E+02  0.000E+00  0.269  0.465
  10    -2.00    6.40     6.78    5.166E+02  1.022E+02  2.751E+01  0.000E+00         0.499

  11    -2.00    0.00     0.00    0.000E+00  6.225E+02  3.412E+02  0.000E+00  0.280  0.467
  11    -1.20    6.78     6.90    5.206E+02  1.022E+02  2.861E+01  0.000E+00         0.500

  12    -1.20    0.00     0.00    0.000E+00  6.212E+02  3.341E+02  0.000E+00  0.294  0.468
  12    -0.40    6.90     7.01    5.225E+02  1.022E+02  3.008E+01  0.000E+00         0.500

  13    -0.40    0.00     0.00    0.000E+00  3.923E+02  3.225E+02  0.000E+00  0.300  0.474
  13     0.40    7.01     7.01    3.178E+02  1.022E+02  3.064E+01  0.000E+00         0.662

  14     0.40    0.00     0.00    0.000E+00  1.629E+02  3.133E+02  0.000E+00  0.295  0.476
  14     1.20    7.01     6.90    1.113E+02  1.022E+02  3.010E+01  0.000E+00         0.501

  15     1.20    0.00     0.00    0.000E+00  1.596E+02  3.039E+02  0.000E+00  0.290  0.478
  15     2.00    6.90     6.78    1.094E+02  1.022E+02  2.967E+01  0.000E+00         0.501

  16     2.00    0.00     0.00    0.000E+00  2.116E+02  2.966E+02  0.000E+00  0.269  0.475
  16     2.80    6.78     6.40    1.054E+02  1.022E+02  2.752E+01  0.000E+00         0.505

  17     2.80    0.00     0.00    0.000E+00  2.011E+02  2.890E+02  0.000E+00  0.249  0.473
  17     3.60    6.40     6.02    9.936E+01  1.022E+02  2.549E+01  0.000E+00         0.505
```

Test example no. : 1

18	3.60	0.00	0.00	0.000E+00	2.247E+02	2.806E+02	0.000E+00	0.219	0.469
18	4.40	6.02	5.46	9.187E+01	1.022E+02	2.240E+01	0.000E+00		0.508
19	4.40	0.00	0.00	0.000E+00	2.405E+02	2.695E+02	0.000E+00	0.179	0.468
19	5.20	5.46	4.73	8.157E+01	1.022E+02	1.826E+01	0.000E+00		0.512
20	5.20	0.00	0.00	0.000E+00	2.177E+02	2.586E+02	0.000E+00	0.139	0.465
20	6.00	4.73	4.00	6.986E+01	1.022E+02	1.421E+01	0.000E+00		0.514
21	6.00	0.00	0.00	0.000E+00	2.060E+02	2.462E+02	0.000E+00	0.096	0.462
21	6.80	4.00	3.20	5.760E+01	1.022E+02	9.826E+00	0.000E+00		0.519
22	6.80	0.00	0.00	0.000E+00	1.809E+02	2.339E+02	0.000E+00	0.054	0.454
22	7.60	3.20	2.40	4.480E+01	1.022E+02	5.531E+00	0.000E+00		0.524
23	7.60	0.00	0.00	0.000E+00	1.561E+02	2.216E+02	0.000E+00	0.013	0.431
23	8.40	2.40	1.60	3.200E+01	1.022E+02	1.333E+00	0.000E+00		0.533
24	8.40	0.00	0.00	0.000E+00	1.316E+02	2.094E+02	0.000E+00	-0.027	0.329
24	9.20	1.60	0.80	1.920E+01	1.022E+02	-2.755E+00	0.000E+00		0.556
25	9.20	0.00	0.00	0.000E+00	1.074E+02	-7.650E-12	0.000E+00	0.000	0.500
25	10.00	0.80	0.00	6.400E+00	1.022E+02	-5.533E-10	0.000E+00		0.666

TEST EXAMPLE : 2

Strip Loading on Weight- and Cohesionless Sand

The case analysed is shown on the figure below. The sand has no weight and no cohesion. The surface loading of 1840 kPa corresponds to the theoretical solution for PHI = 30 degrees and outside surface loading of 100 kPa.

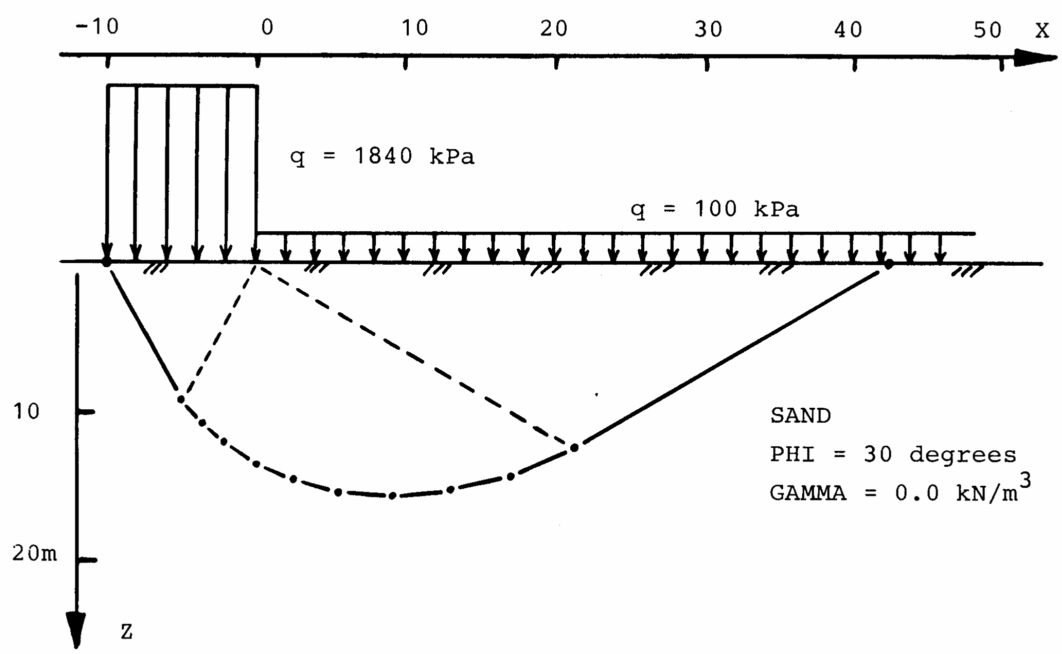


Figure C.2.1 : Test Example 2, Strip Loading on Weightless Sand

Test Example 2 Results

LOCATION OF CRITICAL SHEAR SURFACE

The given general surface with R = 0, 0, 1.0 was "stretched" by the same amounts in the X- and Z-directions, and the safety factor and the score computed. Control parameters used were :

IDEFTO	NUMSLC	H3	ROUGHNESS	R1 R2 R3
31	25	0 0	0 0 1	

XMULT	ZMULT	SF	SCORE	RFACT
0.80	0.80	1.017	0.000	0.50
0.90	0.90	0.987	0.000	0.40
1.00	1.00	0.984	0.000	0.40
1.10	1.10	0.987	0.000	0.40
1.20	1.20	1.010	0.000	0.50

From the above table it is observed that the theoretical shear surface gives the lowest safety factor.

EFFECT OF INTER-SLICE ROUGHNESS ASSUMPTION

Using the above critical surface and control parameters the following results were found.

R1	R2	R3	SF	SCORE	RFACT
0	0	0	0.928	0.000	1.00
1	0	0	0.979	0.000	0.60
0	1	0	0.928	0.000	0.00
0	0	1	0.984	0.000	0.40
1	1	0	0.941	0.000	0.20
1	0	1	0.973	0.000	0.20
0	1	1	0.937	0.000	0.10
1	1	1	0.947	0.000	0.10

It follows that R = 0,0,1 results in a solution that is within 2 % of the theoretical one. All results are within 7 % of the correct value, and again BEAST seems to give results on the low side. The use of the zero score solution with the highest safety factor therefore seems to be justified.

The detailed trace output for the case with R = 0,0,1 is shown below.

LOOP1	R.FACTOR	SF.MOM	A	B	SF.ALL	SCORE
1	0.00	0.903	0.966	0.222	0.928	0.000
2	0.10	0.923	0.988	0.086	0.941	0.000
3	0.20	0.945	1.008	-0.025	0.955	0.000
4	0.30	0.966	1.026	-0.118	0.969	0.000
5	0.40	0.988	1.043	-0.197	0.984	0.000
6	0.50	1.010	1.058	-0.265	0.999	0.002
7	0.60	1.033	1.072	-0.324	1.014	0.037
8	0.70	1.056	1.085	-0.377	1.030	0.102
9	0.80	1.079	1.098	-0.424	1.045	0.229
10	0.90	1.102	1.110	-0.467	1.061	0.349
11	1.00	1.126	1.121	-0.506	1.077	0.527

A control of the effect of number of slices showed that as NUMSLC goes from 5 to 99 the calculated safety factor goes from 0.949 to 0.979.

ANALYSES BY MEANS OF COMBINED SURFACES

The combined surface type 1 (see Figure 4.3.1) was used. The control parameters were the same as those used above. The circle center was assumed located at the soil surface. For each center location, the critical surface was determined using 1 m depth increments.

X.CENTER m	EXIT ANGLE degrees	Z.CRIT m	SF	SCORE	RFACT
5	30	13	1.018	0.000	0.40
6	30	15	1.010	0.000	0.40
7	30	15	0.989	0.000	0.40
8	30	17	1.001	0.000	0.40
7	25	14	0.973	0.000	0.40
7	20	15	0.960	0.000	0.30
7	15	15	0.979	0.000	0.20
8	20	15	0.958	0.000	0.30

The critical surface goes to a depth of 15 m which is close to the theoretical value of 16 m. However, the critical shear surface exit angle is 20 degrees as compared to 30 degrees for the theoretical surface. The lowest safety factor found is 0.96, 4 % lower than theory.

Test Example 2 Input/Output Files

```
BEAST TEST EXAMPLE 2 : STRIP LOADING ON SAND (NQ-FACTOR)     17 APR 2003
SMOOTH FOOTING / WEIGHTLESS SAND
*
* Date         Sign   Log of file modifications
* -----------  ----   ----------------------------------------------------
* 07 Oct 1993  cjfc   Original version, units used are : kN & m
* 17 Apr 2003  cjfc   Modifications for BEAST rev. 4
*

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1     IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   31     IDEFTO    ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
    1     NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
   25     NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0     SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.00 0.00          VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.00 0.00 1.00     VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0     ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    2     JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -2     IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    1     JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000   CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  2.000   CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
    0     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    0     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    0     NUMLAY    NUMBER OF HORIZONTAL LAYERS
    0     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
  TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
  0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

 ****************** MATERIAL PROPERTIES SECTION
    1     NUMMAT    NUMBER OF DIFFERENT MATERIALS
    0     NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
    0     NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
  0.0     CRACKZ    SURFACE OPEN CRACK DEPTH
  0.0     CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
  0.0     PHIREF    FRICTION ANGLE REFERENCE PRESSURE
 EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
  1     0       0      30      0       0       0       0      0     0      0
 TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
  1     0       1.00    1.00    1.00     0
 X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
 NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)

 ****************** PORE-WATER-PRESSURES SECTION
    1     IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
    0     NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
    0     NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
   0.0    FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
   0.0    WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
   0.0    GAMWAT    FREE WATER UNIT WEIGHT
   0.0    GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
    0     PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
  NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)

 ****************** LOAD SECTION
    0     NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
    1     NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
   100    SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
 -100 100 XTOP1,XTOP2         STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
  1.0 1.0 FCTPNT,FCTSIG       POINT AND DISTRIBUTED LOAD FACTORS
```

```
 0.0 1.0 ACCXRT,ACCZRT      ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
 POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
 STRIP     X1        X2      SIGZ1     SIGZ2     TAUX1     TAUX2
   1      -100       0.0     1740      1740        0         0

****************  GIVEN SHEAR SURFACE
  1   12          SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
 -10    -5  -3.78  -2.12    0  2.60  5.66  9.15  13.01  17.15  21.45  42.5  X
   0  8.66 10.39  12.05 13.53 14.74 15.55 15.85 15.51 14.39  12.38    0   Z
   0    0     0      0     0     0     0     0     0     0      0     0   PWP

End of BEAST input file  c:\cjfc\beast\test\data\testx02.002
```

```
# BEAST  Output   Program Version = 17 Apr 2003    Time = 17 APR 2003  11:41:38

 BEAST TEST EXAMPLE 2 : STRIP LOADING ON SAND (NQ-FACTOR)     17 APR 1993
 SMOOTH FOOTING / WEIGHTLESS SAND

 ====================================================  SAFETY FACTOR =   0.984
 SURFACE NO :   1     SUMMARY OF GEOMETRY AND STRESSES
 ====================================================  SOLUTION SCORE=   0.000

 SURFACE TYPE = GENERAL         X-START   Z-START     X-END    Z-END
                                -10.000     0.000    42.500    0.000

 SOLUTION METHOD = BEAST-2003 / EFFECTIVE STRESS ANALYSIS
```

SLICE	X1 / X2	Z1 / Z4	Z2 / Z3	WXT-FRC / WZT-FRC	P-STR / S-STR	E2-STR / T2-STR	U2-STR / U3-STR	ROUGH	H2/Z23 / H3/L34
1	-10.00	0.00	0.00	-3.945E-23	9.216E+02	6.086E+02	2.749E-07	-0.030	0.505
1	-7.90	0.00	3.64	3.860E+03	5.409E+02	-1.066E+01	2.383E-07		0.500
2	-7.90	0.00	0.00	-3.945E-23	8.618E+02	5.892E+02	1.375E-07	0.070	0.505
2	-5.80	3.64	7.27	3.864E+03	5.059E+02	2.412E+01	2.381E-07		0.500
3	-5.80	0.00	0.00	-9.306E-25	8.784E+02	5.740E+02	9.551E-08	0.155	0.499
3	-3.70	7.27	10.47	3.864E+03	5.156E+02	5.227E+01	2.615E-07		0.500
4	-3.70	0.00	0.00	-1.349E-23	1.114E+03	5.480E+02	8.056E-08	0.200	0.503
4	-1.60	10.47	12.41	3.864E+03	6.542E+02	6.444E+01	3.495E-07		0.500
5	-1.60	0.00	0.00	2.218E-23	9.902E+02	5.026E+02	7.266E-08	0.229	0.524
5	0.50	12.41	13.76	2.994E+03	5.812E+02	6.758E+01	4.006E-07		0.611
6	0.50	0.00	0.00	2.432E-23	4.301E+01	4.686E+02	6.784E-08	0.253	0.536
6	2.60	13.76	14.74	2.100E+02	2.524E+01	6.954E+01	4.317E-07		0.500
7	2.60	0.00	0.00	-7.936E-24	6.747E+01	4.486E+02	6.538E-08	0.266	0.536
7	4.70	14.74	15.30	2.100E+02	3.960E+01	7.004E+01	4.603E-07		0.500
8	4.70	0.00	0.00	1.314E-23	8.192E+01	4.339E+02	6.391E-08	0.274	0.530
8	6.80	15.30	15.65	2.100E+02	4.809E+01	6.981E+01	4.696E-07		0.500
9	6.80	0.00	0.00	-3.916E-24	9.572E+01	4.225E+02	6.318E-08	0.278	0.522
9	8.90	15.65	15.83	2.100E+02	5.618E+01	6.894E+01	4.744E-07		0.500
10	8.90	0.00	0.00	-5.286E-24	1.273E+02	4.152E+02	6.375E-08	0.273	0.510
10	11.00	15.83	15.69	2.100E+02	7.471E+01	6.659E+01	4.751E-07		0.500
11	11.00	0.00	0.00	7.949E-25	1.327E+02	4.083E+02	6.458E-08	0.267	0.497
11	13.10	15.69	15.49	2.100E+02	7.788E+01	6.403E+01	4.740E-07		0.500
12	13.10	0.00	0.00	1.763E-23	1.814E+02	4.020E+02	6.704E-08	0.250	0.483
12	15.20	15.49	14.92	2.100E+02	1.065E+02	5.907E+01	4.597E-07		0.500
13	15.20	0.00	0.00	2.505E-23	1.807E+02	3.957E+02	6.983E-08	0.233	0.468
13	17.30	14.92	14.32	2.100E+02	1.060E+02	5.413E+01	4.580E-07		0.500
14	17.30	0.00	0.00	-1.678E-23	2.479E+02	3.836E+02	7.497E-08	0.202	0.458
14	19.40	14.32	13.34	2.100E+02	1.455E+02	4.553E+01	4.314E-07		0.500
15	19.40	0.00	0.00	1.417E-23	2.331E+02	3.724E+02	8.097E-08	0.171	0.446
15	21.50	13.34	12.35	2.100E+02	1.368E+02	3.748E+01	4.309E-07		0.500
16	21.50	0.00	0.00	4.234E-23	2.727E+02	3.532E+02	8.996E-08	0.129	0.441
16	23.60	12.35	11.12	2.100E+02	1.601E+02	2.681E+01	4.105E-07		0.500
17	23.60	0.00	0.00	-3.779E-23	2.465E+02	3.358E+02	1.012E-07	0.087	0.436
17	25.70	11.12	9.88	2.100E+02	1.447E+02	1.710E+01	4.105E-07		0.500

Test example no. : 2

SLICE	X1 X2	Z1 Z4	Z2 Z3	WXT-FRC WZT-FRC	P-STR S-STR	E2-STR T2-STR	U2-STR U3-STR	ROUGH	H2/Z23 H3/L34
18	25.70	0.00	0.00	-3.779E-23	2.238E+02	3.199E+02	1.157E-07	0.044	0.430
18	27.80	9.88	8.65	2.100E+02	1.314E+02	8.242E+00	4.105E-07		0.500
19	27.80	0.00	0.00	5.263E-23	2.039E+02	3.053E+02	1.349E-07	0.000	0.423
19	29.90	8.65	7.41	2.100E+02	1.197E+02	1.261E-01	4.105E-07		0.500
20	29.90	0.00	0.00	5.263E-23	1.863E+02	2.919E+02	1.619E-07	-0.043	0.416
20	32.00	7.41	6.18	2.100E+02	1.094E+02	-7.336E+00	4.105E-07		0.500
21	32.00	0.00	0.00	-3.779E-23	1.709E+02	2.796E+02	2.024E-07	-0.087	0.409
21	34.10	6.18	4.94	2.100E+02	1.003E+02	-1.422E+01	4.105E-07		0.500
22	34.10	0.00	0.00	5.263E-23	1.571E+02	2.681E+02	2.699E-07	-0.131	0.401
22	36.20	4.94	3.71	2.100E+02	9.222E+01	-2.058E+01	4.105E-07		0.500
23	36.20	0.00	0.00	-4.808E-23	1.448E+02	2.575E+02	4.048E-07	-0.175	0.394
23	38.30	3.71	2.47	2.100E+02	8.502E+01	-2.649E+01	4.105E-07		0.500
24	38.30	0.00	0.00	-4.808E-23	1.339E+02	2.475E+02	8.097E-07	-0.220	0.390
24	40.40	2.47	1.24	2.100E+02	7.857E+01	-3.197E+01	4.105E-07		0.500
25	40.40	0.00	0.00	-4.808E-23	1.240E+02	2.537E-09	8.097E-04	0.000	0.500
25	42.50	1.24	0.00	2.098E+02	7.277E+01	6.577E-09	4.109E-07		0.500

TEST EXAMPLE : 3

Strip Loading on Cohesionless Sand with Self Weight.

The case analysed is shown on Figure C.3.1. The sand has self weight and friction but no cohesion. No generally accepted theoretical solution exists for this case. J. Brinch Hansen (1970) gives the following solution :

SIGavr = 0.5 * GAMMA * B * NGAMMA (C.3.1)

where

SIGavr = Average vertical stress
GAMMA = Soil unit weight
B = Footing Width
NGAMMA = Bearing capacity factor, = 33.92 for PHI = 35 degrees.

SIGavr = 0.5 * 10 kN/m^3 * 10 m * 33.92 = 1696 kPa

The NGAMMA solution given by Bent Hansen (1976) for this case is 34.5. The difference in terms of the safety factor on tan(PHI) is less than 1 %.

The first group of runs were carried out to determine the critical shear surface location for the combined surface shown on Figure C.3.1. Control parameters used were :

```
IDEFTO   NUMSLC   H3    ROUGHNESS R1 R2 R3
  31       25     0 0         0  0  1
```

The critical surface was found to be :

XC = 14 m SF = 0.995

ZMAX = 11 m SCORE = 0.007

BETA = 20 degrees R.factor = 0.20

The detailed trace output for the critical surface is shown below.

R.factor	SF.mom	A	B	SF.all	Score
0.00	0.944	0.947	0.423	0.975	0.016
0.10	0.964	0.970	0.234	0.985	0.010
0.20	0.986	0.991	0.076	0.995	0.007
0.30	1.009	1.009	-0.059	1.007	0.040
0.40	1.033	1.026	-0.176	1.020	0.242
0.50	1.058	1.041	-0.279	1.034	0.408
0.60	1.085	1.056	-0.371	1.049	0.622
0.70	1.113	1.069	-0.454	1.064	0.762
0.80	1.142	1.082	-0.531	1.079	0.885
0.90	1.171	1.095	-0.601	1.095	0.998
1.00	1.201	1.107	-0.667	1.111	1.101

A control of the effect of number of slices showed that as NUMSLC goes from 5 to 99 the calculated safety factor goes from 0.977 to 0.990, with a maximum of 1.012 found for 10 slices. The effect of the initial roughness R assumption is shown below.

R1	R2	R3	Z.max (m)	SF	Score	R.factor
0	0	0	11	0.975	0.016	0.30
1	0	0	11	0.975	0.016	0.00
0	1	0	11	0.975	0.016	0.00
0	0	1	11	0.995	0.007	0.20
1	1	0	11	0.975	0.016	0.00
1	0	1	11	0.992	0.012	0.10
0	1	1	11	0.982	0.011	0.10
1	1	1	11	0.991	0.015	0.10

The BEAST solution for this case thus is a safety factor of 0.995, which confirms the NGAMMA formula given by J. Brinch Hansen (1970). The details of this solution is shown below.

Test Example 2 Input/Output Files

```
BEAST TEST EXAMPLE 3 : STRIP LOADING ON SAND (NGAMMA-FACTOR)     17 APR 2003
ROUGH FOOTING / 10.0M WIDE / SAND WITH WEIGHT
*
* Date         Sign   Log of file modifications
* -----------  ----   ----------------------------------------------------
* 07 Oct 1993  cjfc   Original version, units used are : kN & m
* 17 Apr 2003  cjfc   Modifications for BEAST rev. 4
*

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1     IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   31     IDEFTO    ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
    0     NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
   25     NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0     SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.00 0.00          VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.00 0.00 1.00     VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0     ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    2     JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -2     IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    1     JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000   CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  2.000   CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
    0     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    0     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    0     NUMLAY    NUMBER OF HORIZONTAL LAYERS
    0     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
  TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
  0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

 ****************** MATERIAL PROPERTIES SECTION
    1     NUMMAT    NUMBER OF DIFFERENT MATERIALS
    0     NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
```

```
  46----     0     NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
  47----   0.0     CRACKZ    SURFACE OPEN CRACK DEPTH
  48----   0.0     CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
  49----   0.0     PHIREF    FRICTION ANGLE REFERENCE PRESSURE
  50----  EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
  51----  MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
  52----   1    10      0      35      0       0       0      0      0     0     0
  53----  TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
  54----  MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
  55----   1    0       1.00    1.00    1.00     0
  56----  X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
  57----  NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)
  58----
  59----  ****************** PORE-WATER-PRESSURES SECTION
  60----     1     IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
  61----     0     NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
  62----     0     NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
  63----    0.0    FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
  64----    0.0    WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
  65----    0.0    GAMWAT    FREE WATER UNIT WEIGHT
  66----    0.0    GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
  67----     0     PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
  68---- X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
  69----   NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)
  70----
  71----  ****************** LOAD SECTION
  72----     0     NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
  73----     2     NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
  74----    0.0    SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
  75----  -100 100 XTOP1,XTOP2         STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
  76----   1.0 1.0 FCTPNT,FCTSIG       POINT AND DISTRIBUTED LOAD FACTORS
  77----   0.0 1.0 ACCXRT,ACCZRT       ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
  78----   POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
  79----   STRIP     X1        X2      SIGZ1     SIGZ2     TAUX1     TAUX2
  80----     1        0         5         0      3392        0         0
  81----     2        5        10      3392         0        0         0
  82----
  83---- End of BEAST input file  c:\cjfc\beast\test\data\testx03.002


# BEAST  Output   Program Version = 18 Apr 2003    Time = 18 APR 2003  11:20:04

 BEAST TEST EXAMPLE 3 : STRIP LOADING ON SAND (NGAMMA-FACTOR)     17 APR 2003
 ROUGH FOOTING / 10.0M WIDE / SAND WITH WEIGHT

 =====================================================  SAFETY FACTOR =   0.995
 SURFACE NO :   7     SUMMARY OF GEOMETRY AND STRESSES
 =====================================================  SOLUTION SCORE=   0.007

 SURFACE TYPE = COMBINED-1     XSURF1 X-CENTER Z-CENTER  RADIUS  ANGLE2
                CNTR ABOVE      0.000  14.000    0.000   11.000  -20.0

 SOLUTION METHOD = BEAST-2003 / EFFECTIVE STRESS ANALYSIS

 SLICE     X1       Z1       Z2      WXT-FRC    P-STR      E2-STR     U2-STR    ROUGH  H2/Z23
           X2       Z4       Z3      WZT-FRC    S-STR      T2-STR     U3-STR           H3/L34

   1      0.00     0.00     0.00    3.934E-23  3.306E+02  1.473E+02  4.263E-07  0.099  0.315
   1      1.85     0.00     2.35    1.179E+03  2.326E+02  1.021E+01  3.353E-07         0.334

   2      1.85     0.00     0.00    3.934E-23  9.815E+02  2.925E+02  2.132E-07  0.132  0.312
   2      3.69     2.35     4.69    3.535E+03  6.905E+02  2.708E+01  3.350E-07         0.444

   3      3.69     0.00     0.00   -6.979E-24  1.567E+03  4.270E+02  1.423E-07  0.165  0.313
   3      5.54     4.69     7.03    5.693E+03  1.103E+03  4.947E+01  3.356E-07         0.479

   4      5.54     0.00     0.00    7.238E-24  1.435E+03  4.166E+02  1.138E-07  0.194  0.364
   4      7.39     7.03     8.79    4.577E+03  1.009E+03  5.682E+01  3.921E-07         0.542

   5      7.39     0.00     0.00    3.950E-23  8.575E+02  3.543E+02  1.009E-07  0.214  0.425
   5      9.23     8.79     9.91    2.290E+03  6.033E+02  5.328E+01  4.626E-07         0.583

   6      9.23     0.00     0.00   -1.326E-23  1.601E+02  3.220E+02  9.430E-08  0.226  0.447
   6     11.08     9.91    10.60    3.891E+02  1.127E+02  5.127E+01  5.072E-07         0.667

   7     11.08     0.00     0.00    3.322E-24  9.531E+01  3.036E+02  9.135E-08  0.233  0.449
   7     12.93    10.60    10.95    1.990E+02  6.705E+01  4.967E+01  5.325E-07         0.497

   8     12.93     0.00     0.00    3.748E-25  1.213E+02  2.888E+02  9.114E-08  0.233  0.444
   8     14.77    10.95    10.97    2.024E+02  8.536E+01  4.738E+01  5.415E-07         0.500

   9     14.77     0.00     0.00   -1.305E-23  1.515E+02  2.741E+02  9.360E-08  0.229  0.436
   9     16.62    10.97    10.68    1.999E+02  1.066E+02  4.408E+01  5.351E-07         0.502
```

Test example no. : 3

SLICE	X1	Z1	Z2	WXT-FRC	P-STR	E2-STR	U2-STR	ROUGH	H2/Z23
	X2	Z4	Z3	WZT-FRC	S-STR	T2-STR	U3-STR		H3/L34
10	16.62	0.00	0.00	-1.838E-23	1.869E+02	2.552E+02	9.920E-08	0.219	0.431
10	18.46	10.68	10.08	1.917E+02	1.315E+02	3.936E+01	5.149E-07		0.505
11	18.46	0.00	0.00	2.417E-23	1.832E+02	2.351E+02	1.063E-07	0.209	0.428
11	20.31	10.08	9.41	1.799E+02	1.289E+02	3.455E+01	5.089E-07		0.506
12	20.31	0.00	0.00	2.417E-23	1.670E+02	2.155E+02	1.145E-07	0.199	0.424
12	22.16	9.41	8.74	1.675E+02	1.175E+02	3.012E+01	5.089E-07		0.506
13	22.16	0.00	0.00	2.417E-23	1.516E+02	1.964E+02	1.240E-07	0.189	0.421
13	24.00	8.74	8.06	1.551E+02	1.066E+02	2.605E+01	5.089E-07		0.507
14	24.00	0.00	0.00	2.417E-23	1.367E+02	1.778E+02	1.353E-07	0.178	0.418
14	25.85	8.06	7.39	1.427E+02	9.618E+01	2.233E+01	5.089E-07		0.507
15	25.85	0.00	0.00	-1.075E-23	1.224E+02	1.596E+02	1.488E-07	0.168	0.415
15	27.70	7.39	6.72	1.303E+02	8.613E+01	1.892E+01	5.089E-07		0.508
16	27.70	0.00	0.00	2.417E-23	1.087E+02	1.420E+02	1.653E-07	0.159	0.412
16	29.54	6.72	6.05	1.179E+02	7.646E+01	1.584E+01	5.089E-07		0.509
17	29.54	0.00	0.00	2.417E-23	9.543E+01	1.247E+02	1.860E-07	0.149	0.409
17	31.39	6.05	5.38	1.055E+02	6.714E+01	1.306E+01	5.089E-07		0.510
18	31.39	0.00	0.00	2.417E-23	8.268E+01	1.079E+02	2.126E-07	0.139	0.406
18	33.24	5.38	4.70	9.307E+01	5.817E+01	1.056E+01	5.089E-07		0.511
19	33.24	0.00	0.00	1.647E-23	7.039E+01	9.147E+01	2.480E-07	0.130	0.403
19	35.08	4.70	4.03	8.066E+01	4.953E+01	8.346E+00	5.089E-07		0.513
20	35.08	0.00	0.00	-1.848E-23	5.854E+01	7.542E+01	2.976E-07	0.121	0.401
20	36.93	4.03	3.36	6.825E+01	4.119E+01	6.396E+00	5.089E-07		0.515
21	36.93	0.00	0.00	2.417E-23	4.710E+01	5.974E+01	3.720E-07	0.112	0.398
21	38.78	3.36	2.69	5.584E+01	3.314E+01	4.704E+00	5.089E-07		0.519
22	38.78	0.00	0.00	2.417E-23	3.604E+01	4.442E+01	4.960E-07	0.104	0.397
22	40.62	2.69	2.02	4.343E+01	2.536E+01	3.257E+00	5.089E-07		0.524
23	40.62	0.00	0.00	-2.363E-23	2.536E+01	2.944E+01	7.440E-07	0.099	0.395
23	42.47	2.02	1.34	3.102E+01	1.784E+01	2.048E+00	5.089E-07		0.533
24	42.47	0.00	0.00	-2.619E-23	1.503E+01	1.478E+01	1.488E-06	0.000	0.371
24	44.32	1.34	0.67	1.861E+01	1.058E+01	1.068E+00	5.089E-07		0.556
25	44.32	0.00	0.00	2.417E-23	5.044E+00	-1.089E-08	1.488E-03	0.000	0.500
25	46.16	0.67	0.00	6.205E+00	3.549E+00	-1.488E-08	5.094E-07		0.676

Test example no. : 3

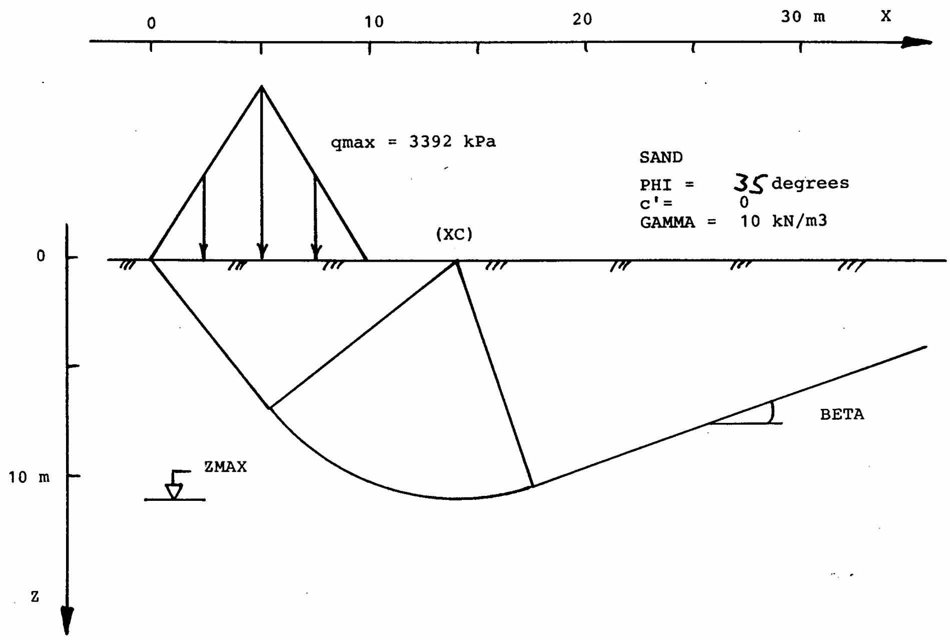


Figure C.3.1

Test example 3, strip footing on sand with self weight

TEST EXAMPLE : 4

Offshore Platform on Clay.

This case is taken from the paper by Lauritzsen and Schjetne (1976). The structure considered is a typical Condeep platform from the Brent/Statfjord area in the North Sea. Figure C.4.1 shows main geometry, loads and undrained shear strength (Su0) values. Isotropic shear strength is assumed.

Note that the overturning moment is taken into the analysis as a linear variation in the vertical stress against the base, rather than by use of the effective area concept.

Side shear forces has been assumed to act on the soil body (not on the platform skirts) with a value of 0.5 times the maximum possible value.

Results

The below solutions were generated with R = 0,0,1 and H3 = 0.0. Input value of IDCASE was 32, i.e. BEAST 2003 method and total stress analysis. The two types of combined surfaces that were tried are shown on Figure 4.3.1 in the main report.

COMBINED SURFACE TYPE 1 (CENTER ABOVE)

The circle center was assumed located at (X=88.3 , Z=3.5). The critical surface goes to Z = 17 m and has safety factor 2.36.

COMBINED SURFACE TYPE 2 (CENTER BELOW)

The critical surface has its lower circle center at (X=10 , Z=230) and gives a safety factor of 2.17.

The above agrees well with the results quoted by Lauritzsen and Schjetne (1976). For the same case they find a safety factor variation of 2.15 to 2.49 depending upon the analysis method used.

Test Example 4 Input File

```
BEAST TEST EXAMPLE 4 : OFFSHORE PLATFORM ON CLAY (LAURITZSEN & SCHJETNE 1976)
ISOTROPIC CLAY STRENGTH         17 APR 2003
*
* Date          Sign   Log of file modifications
* -----------   ----   ----------------------------------------------------
* 14 Oct 1993   cjfc   Original version, units used are : kN & m
* 17 Apr 2003   cjfc   Modifications for BEAST rev. 4
*

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1      IDTYP      SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   32      IDEFTO     ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
    0      NUMGEN     NUMBER OF GENERAL SHEAR SURFACES
   25      NUMSLC     NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.011    SIDSHR     SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.00 0.00            VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.00 0.00 1.00       VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0      ITENSP     ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    1      ITENSE     ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    2      JPRINT     TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -2      IPRTTP     FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    1      JPLOT      CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000    CRTFRC     CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  2.000    CRTSCR     CONVERGENCE CRITERION , SOLUTION SCORE
```

```
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
    4     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    0     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    0     NUMLAY    NUMBER OF HORIZONTAL LAYERS
    0     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
  -100        3.5       100    1
   88.3       3.5       100    1
   88.4       0.0       100    1
   500        0.0       100    0
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
  TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
  0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

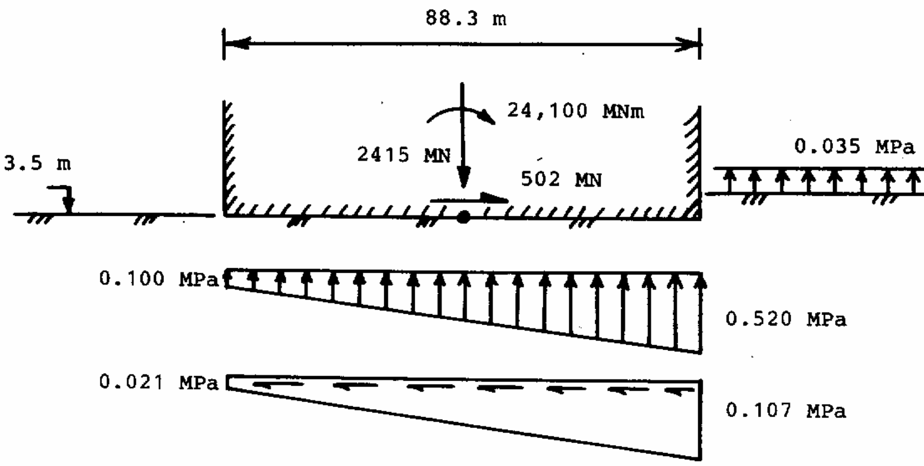
 ****************** MATERIAL PROPERTIES SECTION
    1     NUMMAT    NUMBER OF DIFFERENT MATERIALS
    1     NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
    0     NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
  0.0     CRACKZ    SURFACE OPEN CRACK DEPTH
  0.0     CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
  0.0     PHIREF    FRICTION ANGLE REFERENCE PRESSURE
 EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
  1     0       0      0       0       0       0      0      0     0     0
 TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
  1    .020    1.00    1.00    1.00     0.0
 X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
  1        0.0      7        0.0   2.0   5.5  13.0  17.0  19.5  30.0   Z
                             .060  .180  .180 .130  .130  .250  .250   SU0
 NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)

 ****************** PORE-WATER-PRESSURES SECTION
    1     IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
    0     NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
    0     NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
   0.0    FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
    0     WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
   0.0    GAMWAT    FREE WATER UNIT WEIGHT
   0.0    GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
    0     PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
  NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)

 ****************** LOAD SECTION
    0     NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
    2     NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
   0.0    SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
  0.0 0.0 XTOP1,XTOP2         STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
  1.0 1.0 FCTPNT,FCTSIG       POINT AND DISTRIBUTED LOAD FACTORS
  0.0 1.0 ACCXRT,ACCZRT       ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
  POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
  STRIP     X1        X2      SIGZ1     SIGZ2     TAUX1     TAUX2
    1       0       88.3       .100      .520      .021      .107
    2      88.3     200       -.035     -.035       0         0

 **************** GIVEN SHEAR SURFACE
   0   00         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE

End of BEAST input file  c:\cjfc\beast\test\data\testx04.002
```



CLAY
ISOTROPIC STRENGTH

Z,m	Su0,MPa
0.0	.060
2.0	.180
5.5	.180
13.0	.130
17.0	.130
19.5	.250
30.0	.250

Figure C.4.1

Test example 4, offshore platform, s_u analysis, after Lauritzsen & Schjetne (1976)

TEST EXAMPLE : 5

Simple Clay Slope, Constant Su

This case is included to allow a comparison between the BEAST solution and a solution based upon stability diagrams, Janbu (1954) and Hjeldnes (1971).

Figure C.5.1 shows the slope analysed.

Results

Using the above stability charts the safety factor is calculated to be :

$$SF = No * Su / Pd \qquad (C.5.1)$$

$$= 6.3 * 100 / 566 = 1.11$$

Critical circle center is at XC = 18 m and ZC = -13 m.

The simplified BEAST solution (circles and Su-analysis, moment equilibrium only) gave :

ALL CIRCLES TOUCH LEVEL	CRITICAL CIRCLE X-CENTER	CRITICAL CIRCLE Z-CENTER	SF	
28.00 m	15	-19	1.146	
29.00 m	14	-16	1.143	
30.00 m	13	-17	1.143	
31.00 m	13	-16	1.167	(Non circular)

It is seen that there is good agreement w.r.t. the safety factor, and reasonable agreement for the location of the critical circle center.

Test Example 5 Input File

```
BEAST TEST EXAMPLE 5 : SIMPLE CLAY SLOPE  SU-ANALYSIS     18 APR 2003
BETA=30DGR H=22M DROCK=8M HW=7M DCRCK=4M GAM=20KN/M3 SU=100KPA
*
* Date         Sign   Log of file modifications
* -----------  ----   ----------------------------------------------------
* 12 Oct 1993  cjfc   Original version, units used are : kN & m
* 18 Apr 2003  cjfc   Modifications for BEAST rev. 4
*

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1     IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   02     IDEFTO    ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
    0     NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
   25     NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0     SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.00 0.00          VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.00 0.00 1.00     VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0     ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -2     IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    1     JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000   CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  2.000   CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle
```

Test example no. : 5

```
30----
31----  ****************** GEOMETRY SECTION
32----     4     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
33----     1     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
34----     0     NUMLAY    NUMBER OF HORIZONTAL LAYERS
35----     0     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
36----   X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
37----    -100       0        30     1
38----      0        0        30     1
39----     38       22        30     1
40----    100       22        30     0
41----  00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
42----  00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
43----   LAYER  Z-BOTTOM  MATERIAL-I.D.
44----   TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
45----   0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)
46----
47----  ****************** MATERIAL PROPERTIES SECTION
48----     1     NUMMAT    NUMBER OF DIFFERENT MATERIALS
49----     0     NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
50----     0     NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
51----   4.0     CRACKZ    SURFACE OPEN CRACK DEPTH
52----   4.0     CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
53----   0.0     PHIREF    FRICTION ANGLE REFERENCE PRESSURE
54----  EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
55----  MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
56----   1     20      0      0       0       0       0      0     0     0      0
57----  TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
58----  MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
59----   1     20      1.00    1.00    1.00     100
60----  X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
61----  NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)
62----
63----  ****************** PORE-WATER-PRESSURES SECTION
64----     1     IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
65----     0     NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
66----     0     NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
67----    0.0    FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
68----    15.0   WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
69----    10.0   GAMWAT    FREE WATER UNIT WEIGHT
70----    10.0   GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
71----     0     PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
72---- X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
73----   NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)
74----
75----  ****************** LOAD SECTION
76----     0     NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
77----     0     NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
78----    100    SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
79----   -100 0  XTOP1,XTOP2         STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
80----   1.0 1.0 FCTPNT,FCTSIG       POINT AND DISTRIBUTED LOAD FACTORS
81----   0.0 1.0 ACCXRT,ACCZRT       ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
82----   POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
83----   STRIP     X1        X2      SIGZ1     SIGZ2     TAUX1     TAUX2
84----
85----  **************** GIVEN SHEAR SURFACE
86----    0   00         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
87----
88---- End of BEAST input file  c:\cjfc\beast\test\data\testx05.002
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Test example no. : 5

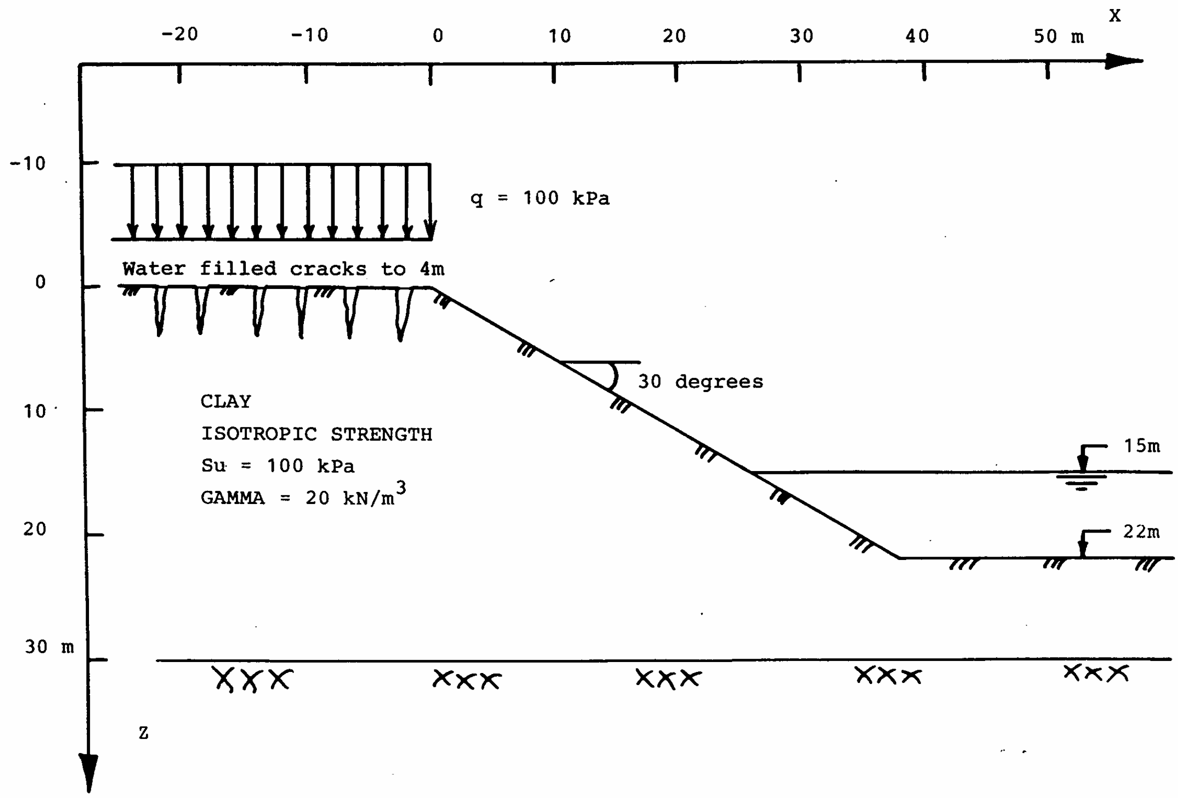


Figure C.5.1

Test example 5, simple clay slope

TEST EXAMPLE : 6

Clay Slope, Effective Stress Analysis

This slope stability case has been analysed by Janbu (1973). The slope has the following properties :

Slope Height	12.5 m
Slope Inclination	1 : 2.5
Total Unit Weight, GAMMA	2.0 t/m^3
Cohesion	1.0 t/m2
Tan(PHI)	0.67
Pore Water Pressure	0.4 * GAMMA * H

where H is the height from the point considered to the soil surface. The BEAST input file for this case is given below.

Results

Janbu (1973) gives a safety factor of 1.49 for this slope. The non-circular surface analysed by Janbu passes through the toe of the slope and is close to circular in shape.

BEAST gives the following results for the critical circular shear surface passing through the toe point (X=31.25m Z=12.5m) with its center at (X=26m Z=-25m) :

R1	R2	R3	SF	Score	R.factor
0	0	0	1.509	0.517	1.00
1	0	0	1.509	0.517	0.00
0	1	0	1.510	0.219	0.30
0	0	1	1.509	0.442	0.50
1	1	0	1.510	0.298	0.30
1	0	1	1.509	0.517	0.00
0	1	1	1.511	0.168	0.60
1	1	1	1.510	0.315	0.20

The BEAST safety factor is thus 1 % higher than the one found by Janbu (1973). The calculated safety factor is in-sensitive to the initial roughness assumption used. This agrees with the findings of Duncan and Wright (1980), who conclude that :

> *"Methods for slope stability analysis which satisfy all conditions of equilibrium give accurate results for all practical conditions. Regardless of the assumption they employ, these methods give values of SF which differ no more than 5 percent from the correct answer."*

Test Example 6 Input File

```
BEAST TEST EXAMPLE 6 : SIMPLE C-PHI SLOPE  (JANBU 1973)    18 APR 2003
H=12.5M  INCL=1:2.5  GAM=2.0T/M3  C=1.0T/M2  PHI=33.8DGR  RU=0.4
*
* Date          Sign   Log of file modifications
* -----------   ----   ---------------------------------------------------
* 12 Oct 1993  cjfc   Original version, units used are : tonnes & metres
* 18 Apr 2003  cjfc   Modifications for BEAST rev. 4
*

 ****************** CONTROL SECTION
   1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
   1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
     1     IDTYP      SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
    31     IDEFTO     ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
     0     NUMGEN     NUMBER OF GENERAL SHEAR SURFACES
    25     NUMSLC     NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
   0.0     SIDSHR     SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
  0.00 0.00           VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
  0.00 0.00 1.00      VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
     0     ITENSP     ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
     0     ITENSE     ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
     2     JPRINT     TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
    -2     IPRTTP     FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
     1     JPLOT      CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
   0.000   CRTFRC     CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
   0.000   CRTSCR     CONVERGENCE CRITERION , SOLUTION SCORE
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
     4     NUMXLN     NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
     4     NUMELZ     NUMBER OF ELEMENTS IN Z-DIRECTION
     0     NUMLAY     NUMBER OF HORIZONTAL LAYERS
     0     NUMTRI     NUMBER OF MATERIAL I.D. TRIANGLES
   X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
     -50       0          30     5
       0       0          30     3
    31.25    12.5         30     2
      50     12.5         30     0
  00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
  00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
   LAYER  Z-BOTTOM  MATERIAL-I.D.
   TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
   0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

 ****************** MATERIAL PROPERTIES SECTION
     1     NUMMAT     NUMBER OF DIFFERENT MATERIALS
     0     NUMXSU     NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
     0     NODSU      NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
   0.0     CRACKZ     SURFACE OPEN CRACK DEPTH
   0.0     CRACKW     WATER DEPTH IN OPEN SURFACE CRACK
   0.0     PHIREF     FRICTION ANGLE REFERENCE PRESSURE
  EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
  MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
   1     2.0    1.0    33.8      0       0      0.4     0      0     0      0
  TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
  MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
   1     0       1.00    1.00    1.00     0
  X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
  NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)

 ****************** PORE-WATER-PRESSURES SECTION
     2     IDPWP      PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
     0     NUMXPW     NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
     0     NODPWP     NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
    0.0    FCTNOD     FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
    0.0    WATERZ     HORIZONTAL WATER TABLE Z-LEVEL
    0.0    GAMWAT     FREE WATER UNIT WEIGHT
    0.0    GAMPWP     PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
     0     PWPMIN     MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
  X-LINE  X-COORD  Z-POINTS   LINE : Z-VALUES / LINE 2 : PWP-VALUES
   NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)
```

Test example no. : 6

```
 ****************** LOAD SECTION
   0     NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
   0     NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
  0.0    SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
 -100 100 XTOP1,XTOP2        STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
  1.0 1.0 FCTPNT,FCTSIG      POINT AND DISTRIBUTED LOAD FACTORS
  0.0 1.0 ACCXRT,ACCZRT      ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
  POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
  STRIP     X1        X2      SIGZ1     SIGZ2     TAUX1     TAUX2
 **************** GIVEN SHEAR SURFACE
  0   00         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
End of BEAST input file  c:\cjfc\beast\test\data\testx06.002
```

TEST EXAMPLE : 7

The Lodalen Slide

A detailed description of this slide is given by Sevaldson (1956). Figure C.7.1 shows a typical cross section with the results of piezometer measurements after the slide took place.

Results

Sevaldson gives an average safety factor of 1.05 for three profiles through the slide area calculated by the Bishop (1955) method. The surface analysed is the observed slip surface that extended a few meters outside the slope toe. Sevaldson finds that the critical circle passes through the toe (x= 50 m , z = -9 m) of the slope and has a safety factor of 1.00.

For toe circles BEAST finds the following critical circle with IDEFTO = 31, NUMSLC = 25 and R taken as 0,0,1.

X - center	41 m
Z - center	-39 m
Safety factor	0.981
Score	0.516
R - factor	0.50

Test Example 7 Input File

```
BEAST TEST EXAMPLE 7 : LODALEN SLIDE   (SEVALDSON 1956)   18 APR 2003
EFFECTIVE STRESS ANALYSIS , PORE PRESSURES GIVEN BY VERTICAL SECTIONS
*
* Date         Sign   Log of file modifications
* -----------  ----   --------------------------------------------------
* 12 Oct 1993  cjfc   Original version, units used are : kN & m
* 18 Apr 2003  cjfc   Modifications for BEAST rev. 4
*

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1     IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   31     IDEFTO    ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
    0     NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
   25     NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0     SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.00 0.00          VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.00 0.00 1.00     VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0     ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    2     JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -2     IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    1     JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000   CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  0.000   CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     1      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
    9     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    6     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    0     NUMLAY    NUMBER OF HORIZONTAL LAYERS
    0     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
 -100.0     -27.0      0.0     1
   10.0     -27.0      0.0     1
   11.5     -26.0      0.0     1
   16.0     -26.0      0.0     1
   20.0     -24.0      0.0     1
```

Test example no. : 7

```
 42----    30.0     -19.0      0.0     1
 43----    40.0     -14.0      0.0     1
 44----    50.0      -9.0      0.0     1
 45----    60.0      -9.0      0.0     0
 46----  00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 47----  00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
 48----   LAYER  Z-BOTTOM  MATERIAL-I.D.
 49----   TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
 50----   0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)
 51----
 52----  ****************** MATERIAL PROPERTIES SECTION
 53----     1     NUMMAT    NUMBER OF DIFFERENT MATERIALS
 54----     0     NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
 55----     0     NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
 56----   1.0     CRACKZ    SURFACE OPEN CRACK DEPTH
 57----   1.0     CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
 58----   0.0     PHIREF    FRICTION ANGLE REFERENCE PRESSURE
 59----  EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 60----  MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
 61----   1    1.91    1.0    27.0     0       0      0.0     0      0     0     0
 62----  TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 63----  MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
 64----   1    0       1.00    1.00    1.00     0
 65----  X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
 66----  NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)
 67----
 68----  ****************** PORE-WATER-PRESSURES SECTION
 69----     2     IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
 70----     6     NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
 71----     0     NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
 72----   0.0     FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
 73----   0.0     WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
 74----   1.0     GAMWAT    FREE WATER UNIT WEIGHT
 75----   0.0     GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
 76----     0     PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
 77---- X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
 78----     1     0.0       5       -23.4  -19.4  -16.9  -12.4  100.0
 79----                               0      4      8     14    123
 80----     2    10.0       5       -22.4  -18.5  -16.0  -11.4  100.0
 81----                               0      4      8     14    123
 82----     3    20.0       5       -20.6  -16.6  -14.0   -9.1  100.0
 83----                               0      4      8     14    121
 84----     4    30.0       5       -17.4  -13.0  -10.0   -4.6  100.0
 85----                               0      4      8     14    118
 86----     5    40.0       5       -13.5   -9.0   -5.9    0.2  100.0
 87----                               0      4      8     14    114
 88----     6    50.0       5        -9.0   -5.4   -2.1    3.9  100.0
 89----                               0      4      8     14    109
 90----   NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)
 91----
 92----  ****************** LOAD SECTION
 93----     0     NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
 94----     0     NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
 95----   0.0     SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
 96----  -100 100 XTOP1,XTOP2         STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
 97----   1.0 1.0 FCTPNT,FCTSIG       POINT AND DISTRIBUTED LOAD FACTORS
 98----   0.0 1.0 ACCXRT,ACCZRT       ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
 99----   POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
100----   STRIP     X1        X2      SIGZ1     SIGZ2     TAUX1     TAUX2
101----
102----  **************** GIVEN SHEAR SURFACE
103----    0    0         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
104----
105---- End of BEAST input file  c:\cjfc\beast\test\data\testx07.002
```

Test example no. : 7

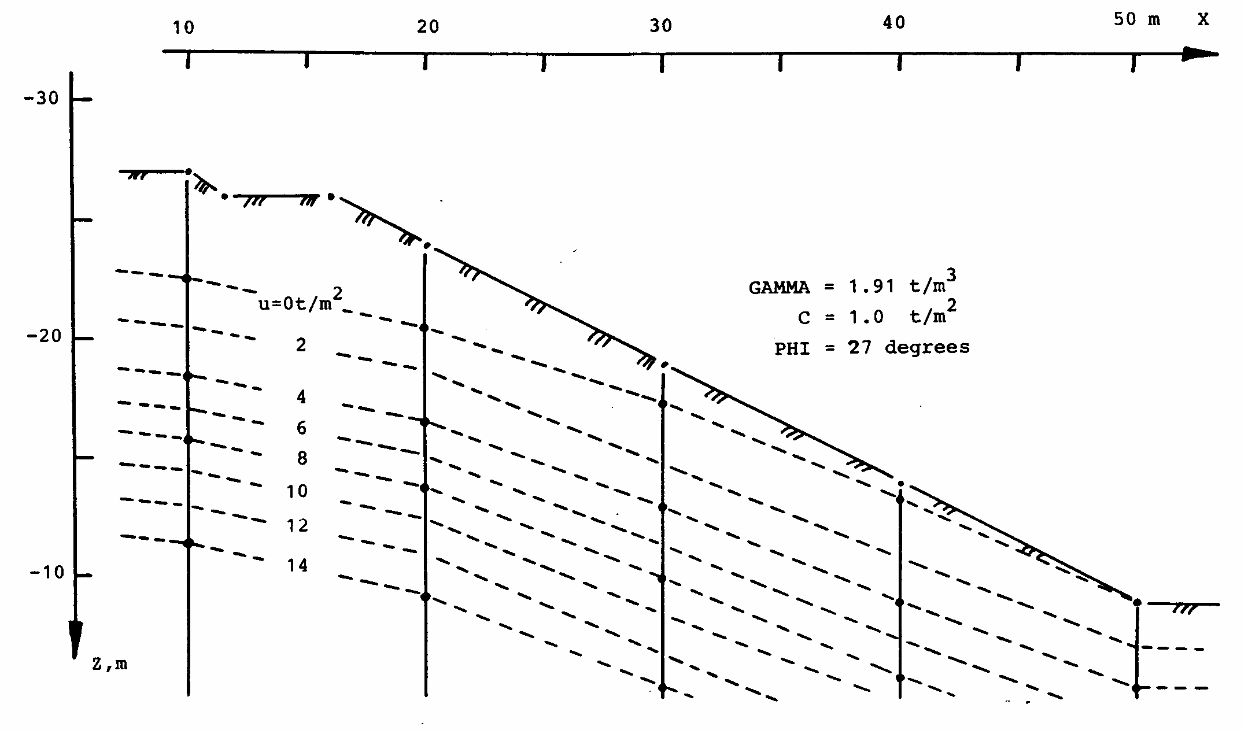


Figure C.7.1

Test example 7, the Lodalen slide, Sevaldson (1956)

TEST EXAMPLE : 8

Rockfill Dam With Central Tilting Core.

Figure C.8.1 shows a sketch of the dam analysed with the location of the five general surfaces to be tried. Four different materials were used to model the cross section. Their properties are given by :

MAT	GAMMA kN/m3	COHSN kN/m2	PHIANG degrees	PHIRED degrees	RU	LOCATION
1	20	0	55.4	6.4	0	Shell, dry
2	23	0	55.4	6.4	0	Shell, sat.
3	23	0	36.9	0.0	0.5	Clay core
4	23	0	52.4	7.4	0	Shell/rock

Note that the shell (rockfill) and the shell/rock interface has a friction angle that depends upon the effective normal stress, see Equation (3.3.6) above.

Results

The five general shear surfaces were analysed with IDEFTO input = 31 and NUMSLC = 0.

SURFACE	SF	SCORE	R-FACTOR
1	2.137	0.500	1.00
2	1.883	0.500	1.00
3	1.695	0.000	0.10
4	1.607	0.000	0.00
5	2.263	0.435	0.80

Test Example 8 Input File

```
BEAST TEST EXAMPLE 8 : ROCKFILL DAM WITH CENTRAL TILTING CORE   18 APR 2003
STRESS DEPENDENT FRICTION FOR SHELL AND FOUNDATION
*
* Date         Sign   Log of file modifications
* -----------  ----   ----------------------------------------------------
* 14 Oct 1993  cjfc   Original version, units used are : kN & m
* 18 Apr 2003  cjfc   Modifications for BEAST rev. 4
*

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1     IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   -1     IDEFTO    ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
    5     NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
   00     NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0     SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.00 0.00          VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.67 0.67 0.00     VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0     ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    2     JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -2     IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    1     JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000   CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  0.000   CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
    5     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    1     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    2     NUMLAY    NUMBER OF HORIZONTAL LAYERS
    2     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
   -220        0         5      1
     -5     -156         5      1
      5     -156         5      1
    250        0       0.01     1
    500        0       0.01     0
```

Test example no. : 8

```
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
    1      -90        1   =  NON-SATURATED SHELL
    2        0        2   =  SATURATED SHELL
  TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
    1          3       92  0       28   0      -5  -163   = CORE MATERIAL
    2          4      250  0      100 9000     90  -5     = FOUNDATION ZONE
  0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)
 ****************** MATERIAL PROPERTIES SECTION
    4     NUMMAT    NUMBER OF DIFFERENT MATERIALS
    0     NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
    0     NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
  0.0     CRACKZ    SURFACE OPEN CRACK DEPTH
  0.0     CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
 100.0    PHIREF    FRICTION ANGLE REFERENCE PRESSURE
 EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
  1    20.0    0.0    55.4    6.4      0      0.0     0      0     0      0
  2    23.0    0.0    55.4    6.4      0      0.0     0      0     0      0
  3    23.0    0.0    36.9    0.0      0     -0.5     0      0     0      0
C   THE NEGATIVE RU ABOVE (PWP=GAM*H*RU) MEANS THAT OTHER PWP CONTRIBUTIONS
C   SHALL NOT BE ADDED
  4    23.0    0.0    52.4    7.4      0      0.0     0      0     0      0
 TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
  1     0       1.00    1.00    1.00     0
  2     0       1.00    1.00    1.00     0
  3     0       1.00    1.00    1.00     0
  4     0       1.00    1.00    1.00     0
 X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
 NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)
 ****************** PORE-WATER-PRESSURES SECTION
    2     IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
    0     NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
    0     NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
   0.0    FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
 -90.0    WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
  10.0    GAMWAT    FREE WATER UNIT WEIGHT
  10.0    GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
    0     PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
  NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)
 ****************** LOAD SECTION
    0     NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
    0     NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
   0.0    SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
 -100 100 XTOP1,XTOP2         STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
  1.0 1.0 FCTPNT,FCTSIG       POINT AND DISTRIBUTED LOAD FACTORS
  0.0 1.0 ACCXRT,ACCZRT       ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
  POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
  STRIP     X1        X2      SIGZ1     SIGZ2     TAUX1     TAUX2
 **************** GIVEN SHEAR SURFACE
   1    3         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
          -5    70    250   X
        -156   -30      0   Z
           0     0      0   PWP
   2    3         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
          -5    60    250   X
        -156   -49      0   Z
           0     0      0   PWP
   3    3         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
          -5    45    250   X
        -156   -74      0   Z
           0     0      0   PWP
   4    3         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
          -5    30    250   X
        -156   -102     0   Z
           0     0      0   PWP
   5    6         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
          -1     1    60    130    210    235   X
        -160   -145 -50      1      1    -10   Z
           0     0      0    0      0      0   PWP
End of BEAST input file  c:\cjfc\beast\test\data\testx08.002
```

Test example no. : 8

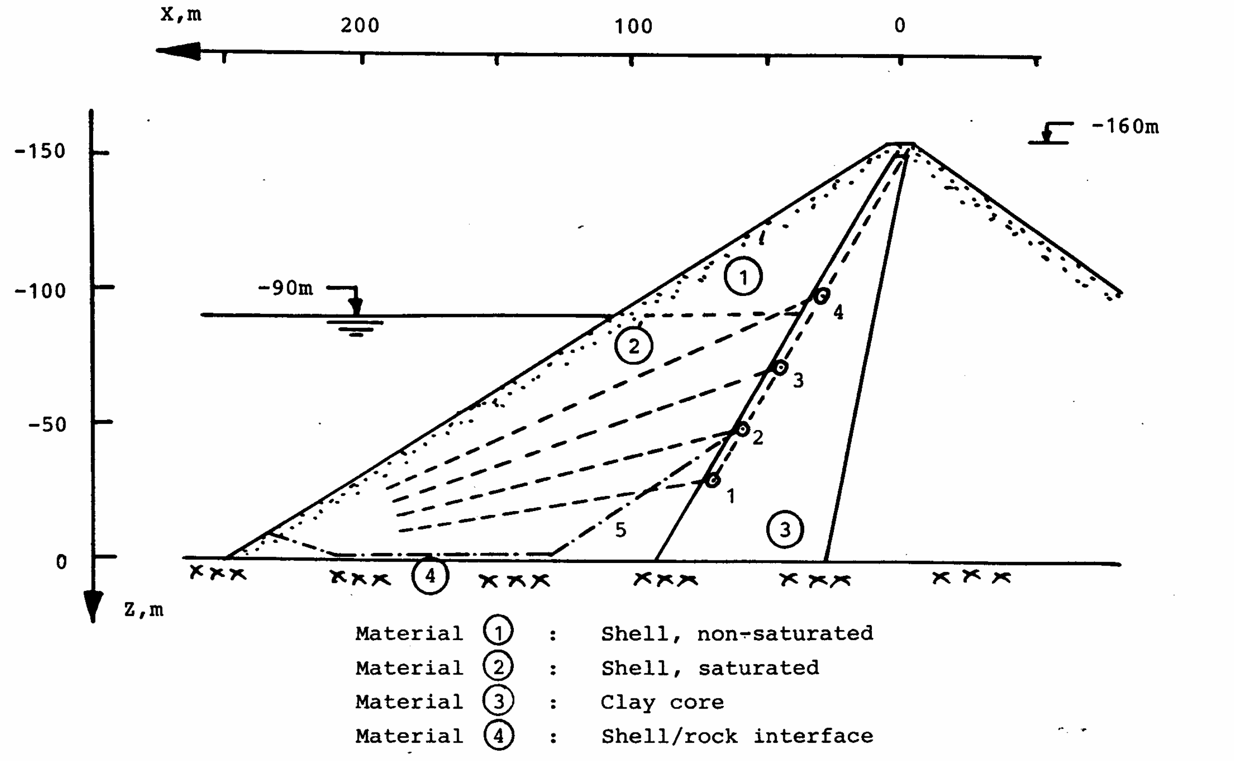


Figure C.8.1

Test example 8, rockfill dam with clay core

TEST EXAMPLE : 9

Active and Passive Earth Pressures Against a Wall.

The case analysed is shown on Figure C.9.1. We want to calculate active and passive earth pressure forces against the wall for a range of values of the wall friction R*tan(PHI).

Results

The earth pressure solutions calculated by BEAST are force equilibrium solutions for the given R values. The interslice roughness was assumed constant and equal to the wall roughness.

The shear surfaces investigated are all planes through the base of the wall at inclination BETA.

WALL ROUGHNESS	SF	SCORE	CRIT.ANGLE BETA, degr	EARTH PRESS FORCE E2, kN
1.00	+1.00	0.395	50	326
0.67	+1.00	0.203	51	346
0.33	+1.00	0.100	53	371
0.00	+1.00	0.100	55	402
-0.33	+1.00	0.100	58	444
-0.67	+1.00	0.100	64	512
-1.00	+1.00	0.100	89.9	749
1.00	-1.00	1.100	22	36,040
0.67	-1.00	1.000	27	15,760
0.33	-1.00	0.350	32	8,211
0.00	-1.00	0.000	39	4,807
-0.33	-1.00	0.100	48	2,944
-0.67	-1.00	0.158	62	1,762
-1.00	-1.00	0.100	89.9	751

The passive earth pressure values are included for demonstration purposes only. In reality the critical passive shear surfaces will not be planes, and the correct answers will be lower than the values shown above.

The active earth pressure force of 346 kN for R=0.67 is found to agree with the theoretical formula given by Terzaghi (1943), based upon Coulomb's original work from 1776.

Test Example 9 Input File

```
(0001)  BEAST TEST EXAMPLE 9 : SIMPLE EARTH PRESSURE CASE   14 OCT 1993
(0002)  UNIFORM SAND SLOPE  PHI=30DGR  GAM=20KN/M3  NO PWP  TAN(DELTA)=0.364
(0003)
(0004)   ****************** CONTROL SECTION
(0005)    1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
(0006)    1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
(0007)      2     IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
(0008)      1     IDEFTO    ANALYSIS TYPE : 1=EFFCTV STRESS 2=TOTAL STRESS 3=COMBINED
(0009)      0     NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
(0010)     10     NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
(0011)    0.0     SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
(0012)   0.00 0.00          VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
(0013)   1.00 1.00 0.00     VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
(0014)      0     ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
(0015)      0     ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
(0016)      0     JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
(0017)      2     IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
(0018)      1     JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
(0019)    0.000   CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
(0020)    2.000   CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
(0021)  C                    = 0.000 : FIND ZERO SCORE SOLUTION WITH HIGHEST SF
(0022)  C                    = 0.001 TO 0.999 : TAKE FIRST SOLUTION WITH LOWER SCORE
(0023)  C                    = 1.000+ : USE INTERSLICE ROUGHNESS FACTOR 1.0
```

```

 ****************** GEOMETRY SECTION
    3     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    1     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    0     NUMLAY    NUMBER OF HORIZONTAL LAYERS
    0     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
    -500      -26.8    100    1
    -100      -26.8    100    1
     100       26.8    100    0
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
  TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
 0.0 10.0 1.00 XWALL,HWALL,RWALL WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

 ****************** MATERIAL PROPERTIES SECTION
    1     NUMMAT    NUMBER OF DIFFERENT MATERIALS
    0     NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
    0     NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
  0.0     CRACKZ    SURFACE OPEN CRACK DEPTH
  0.0     CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
  0.0     PHIREF    FRICTION ANGLE REFERENCE PRESSURE
 EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
  1    20.0    0.0    30.0    0.0      0      0.0     0      0     0      0
 TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
  1     0       1.00    1.00    1.00     0
 X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
 NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)

 ****************** PORE-WATER-PRESSURES SECTION
    1     IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
    0     NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
    0     NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
   0.0    FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
   0.0    WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
   0.0    GAMWAT    FREE WATER UNIT WEIGHT
   0.0    GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
    0     PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
  NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)

 ****************** LOAD SECTION
    0     NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
    0     NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
   0.0    SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
 -100 100 XTOP1,XTOP2         STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
  1.0 1.0 FCTPNT,FCTSIG       POINT AND DISTRIBUTED LOAD FACTORS
  0.0 1.0 ACCXRT,ACCZRT       ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
  POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
  STRIP     X1       X2       SIGZ1     SIGZ2     TAUX1     TAUX2

 **************** GIVEN SHEAR SURFACE
   0    0         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
END OF BEAST INPUT FILE
```

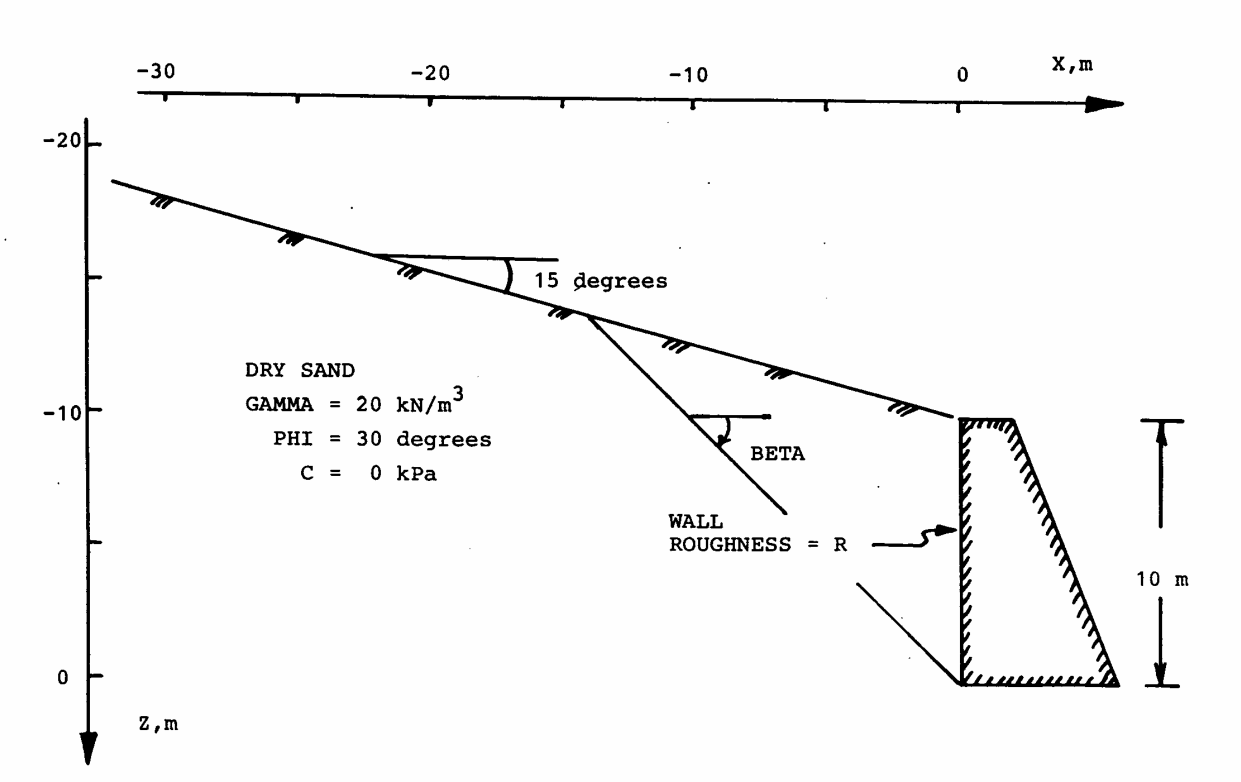


Figure C.9.1

Test example 9, active and passive earth pressures

TEST EXAMPLE : 10

Undrained Effective Stress Analysis , Strip Footing

The example selected is taken from Svanø (1981). Figure C.10.1 shows the case analysed. The horizontal soil surface initially carries a loading of 20 kPa. An additional load of 90 kPa is applied to the 3.7 m wide footing under undrained conditions.

Results

The BEAST solution obtained is given below. The safety factor found, 1.71, is very close to the value of 1.72 reported by Svanø.

Test Example 10 Input File

```
BEAST TEST EXAMPLE 10 :  UNDRAINED EFFECTIVE STRESS ANALYSIS
BEARING CAPACITY , SVAN□ (1981) , FIGURE 5.7    08 OCT 1993 CJFC

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1     IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
    1     IDEFTO    ANALYSIS TYPE : 1=EFFCTV STRESS 2=TOTAL STRESS 3=COMBINED
    1     NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
   10     NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0     SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.50 0.50          VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.50 0.50 0.00     VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0     ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
    2     IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    1     JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000   CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  0.000   CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
C                    = 0.000 : FIND ZERO SCORE SOLUTION WITH HIGHEST SF
C                    = 0.001 TO 0.999 : TAKE FIRST SOLUTION WITH LOWER SCORE
C                    = 1.000+ : USE INTERSLICE ROUGHNESS FACTOR 1.0

 ****************** GEOMETRY SECTION
    0     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    0     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    0     NUMLAY    NUMBER OF HORIZONTAL LAYERS
    0     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
  TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
  0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

 ****************** MATERIAL PROPERTIES SECTION
    1     NUMMAT    NUMBER OF DIFFERENT MATERIALS
    0     NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
    0     NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
  0.0     CRACKZ    SURFACE OPEN CRACK DEPTH
  0.0     CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
  0.0     PHIREF    FRICTION ANGLE REFERENCE PRESSURE
 EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
  1    10.0    9.9    31.0     0       0       0      1.0    1.0   0.5    0.0
 TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
  1    0.0      1.00    1.00    1.00     0
 X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
 NODE    SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)
```

```

  ****************** PORE-WATER-PRESSURES SECTION
     2      IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
     0      NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
     0      NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
    0.0     FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
    0.0     WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
    0.0     GAMWAT    FREE WATER UNIT WEIGHT
    0.0     GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
    0.0     PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
 X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
   NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)

  ****************** LOAD SECTION
     0      NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
     1      NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
   20.0     SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
  -100 100 XTOP1,XTOP2          STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
   1.0 1.0 FCTPNT,FCTSIG        POINT AND DISTRIBUTED LOAD FACTORS
   0.0 1.0 ACCXRT,ACCZRT        ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
   POINT    X-COORD   Z-COORD   X-FORCE   Z-FORCE
   STRIP      X1        X2      SIGZ1     SIGZ2     TAUX1     TAUX2
     1      -100        0         90        90        0         0

  **************** GIVEN SHEAR SURFACE
    1   8           SURFACE NUMBER , NUMBER OF POINTS ON SURFACE
   -3.75    -3.00    -2.00    -1.00    0.00    1.00    2.00    5.40 X-COORDS
    0.0      1.00     1.85     2.40    2.50    2.35    2.00    0.0  Z-COORDS
    0.0      0.0      0.0      0.0     0.0     0.0     0.0     0.0  PWP
 END OF BEAST INPUT FILE
```

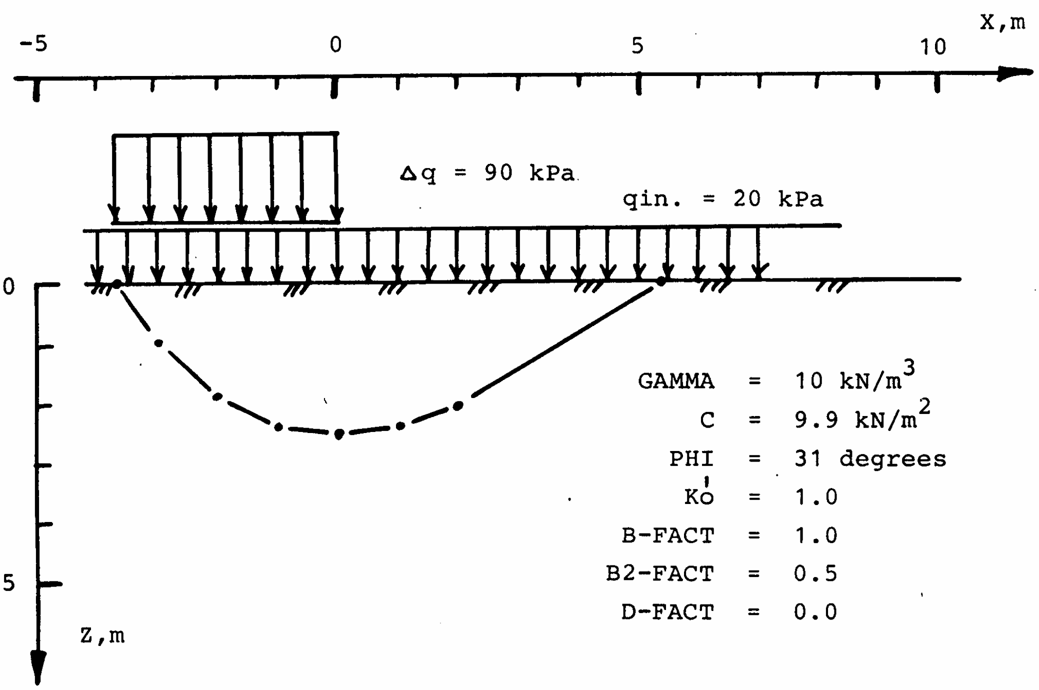


Figure C.10.1

Test example 10, strip footing, UESA solution, from Svanø (1981)

TEST EXAMPLE : 11

Clay Slope, Combined Analysis

This case is included to show results obtained by the Swedish combined analysis method. Figure C.11.1 shows the slope analysed by Sällfors and Larsson (1984).

The figure also shows the critical circles determined by BEAST. These solutions agree well with the values given by the above authors. Calculated safety factors are given below. The BEAST solutions were generated with R = 0,0,1 and 25 slices. All circles pass through (X=80m , Z=0m).

	Beast	Sällfors & Larsson (1984)
Effective stress	1.36	1.50
Total stress	1.31	1.35
Combined analysis	1.12	1.16

Test Example 11 Input File

```
SALLFORS & LARSON (1984)  SLOPE 3      18 APR 2003
COMPARISON BETWEEN TOTAL, EFFECTIVE AND COMBINED ANALYSIS
*
* Date         Sign   Log of file modifications
* -----------  ----   ----------------------------------------------------
* 14 Oct 1993  cjfc   Original version, units used are : kN & m
* 18 Apr 2003  cjfc   Modifications for BEAST rev. 4
*

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1     IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   33     IDEFTO    ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
    0     NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
   25     NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0     SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.00 0.00          VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.00 0.00 1.00     VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0     ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    2     JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -2     IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    1     JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000   CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  0.000   CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
    6     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    1     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    3     NUMLAY    NUMBER OF HORIZONTAL LAYERS
    0     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
    -500     -24       100      1
      10     -24       100      1
      28     -15       100      1
      70      -5       100      1
      78       0       100      1
     500       0       100      0
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
    1      -12       1
    2        0       2
    3      100       3
```

Test example no. : 11

```
 TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
 0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

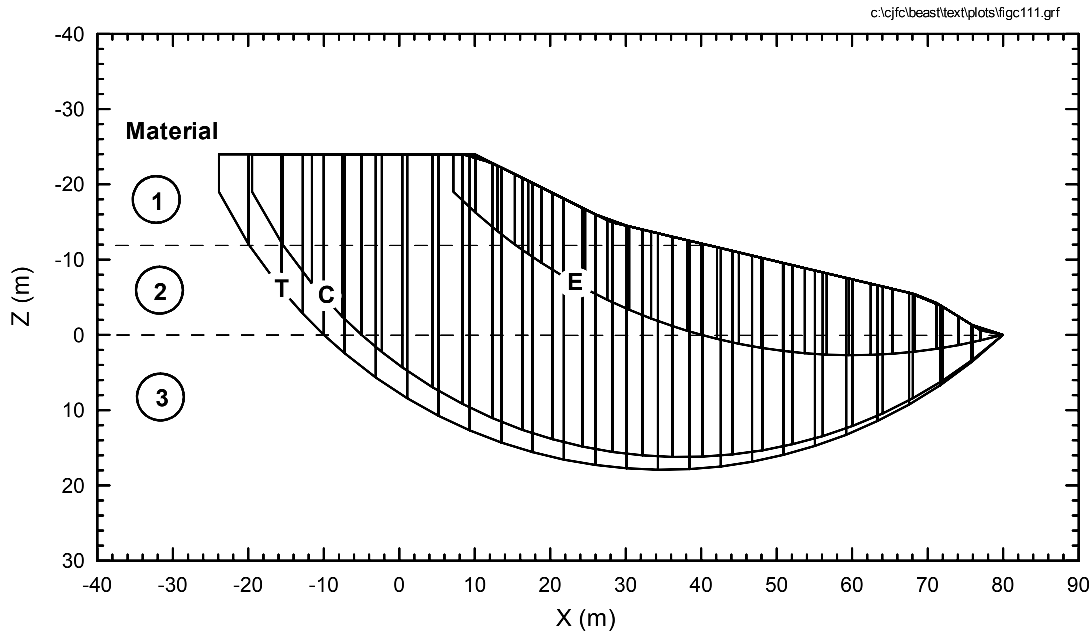
******************  MATERIAL PROPERTIES SECTION
    3      NUMMAT    NUMBER OF DIFFERENT MATERIALS
    1      NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
    0      NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
  5.0      CRACKZ    SURFACE OPEN CRACK DEPTH
  5.0      CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
  0.0      PHIREF    FRICTION ANGLE REFERENCE PRESSURE
EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
 1    19.0   20.0    30.0     0       0      0.0      0      0     0     0
 2    19.0   15.0    30.0     0       0      0.0      0      0     0     0
 3    19.0   10.0    30.0     0       0      0.0      0      0     0     0
TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
 1    19.0     1.00    1.00    1.00      0
 2    19.0     1.00    1.00    1.00      0
 3    19.0     1.00    1.00    1.00      0
X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
   1      0.0       6       -24   -12   0    10   20   50
                            170   130  85    75   85  115
NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)

******************  PORE-WATER-PRESSURES SECTION
    2      IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
    5      NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
    0      NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
   0.0     FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
   0.0     WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
  10.0     GAMWAT    FREE WATER UNIT WEIGHT
   0.0     GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
   0.0     PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
  1       10.0      2       -19.0  81.0
                              0.0  1000
  2       20.0      2       -19.0  81.0
                              0.0  1000
  3       28.0      2       -15.0  85.0
                              0.0  1000
  4       70.0      2        -5.0  95.0
                              0.0  1000
  5       73.2      2        -3.0  97.0
                              0.0  1000
 NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)

******************  LOAD SECTION
    0      NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
    0      NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
   0.0     SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
-100 100 XTOP1,XTOP2           STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
 1.0 1.0 FCTPNT,FCTSIG         POINT AND DISTRIBUTED LOAD FACTORS
 0.0 1.0 ACCXRT,ACCZRT         ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
 POINT   X-COORD  Z-COORD   X-FORCE   Z-FORCE
 STRIP     X1       X2      SIGZ1     SIGZ2     TAUX1     TAUX2

End of BEAST input file  c:\cjfc\beast\test\data\testx11.002
```

Test example no. : 11



Surface E : Effective stress analysis SF = 1.36
Surface T : Total stress analysis SF = 1.31
Surface C : Combined analysis SF = 1.12

Soil material no.	Total unit weight kN/m^2	c' kPa	φ' degrees
1	19	20	30
2	19	15	30
3	19	10	30

Depth Z (m)	-24	-12	0	10	20	50
Su (kPa)	170	130	85	75	85	115

Figure C.11.1

Test example 11, clay slope, comparison between analysis methods

TEST EXAMPLE : 12

Slope With Soil Nails

This case is included in order to demonstrate the use of the soil nail option in BEAST.

Figure C.12.1 shows the slope analysed. Only the geometry after the completion of the construction work is being considered, with and without soil nails. The slope is reinforced by soil nails labelled 1 to 11 on the figure. In addition, 7 vertical piles have been driven through the clay layer, labelled 12 to 18 on the figure.

The geometry for this example, the soil properties and the soil nail data were selected such that "reasonable" safety factors near 1.0 would be calculated. The input values do therefore not in any way represent a good practical choice that could be used in an actual design situation.

Two sets of circular failure surfaces have been considered, shallow surfaces that pass through point A at the slope toe, and deep surfaces that pass through point B outside the embankment.

Results

The calculated safety factors and the critical circle centres for the different cases are summarised in the below table. Point A has co-ordinates (X=54m , Z=24m), point B (X=72m , Z=24m)

Case	Circles pass through point	Presence of soil nails	Circle centre		Safety factor
			X (m)	Z (m)	
1	A	No	63	-19	0.706
2	A	Yes	23	-24	1.179
3	B	No	39	-36	0.827
4	B	Yes, no lateral capacity	33	-46	0.889
5	B	Yes, with lateral capacity	30	-39	1.075

Printed output to file NF16, BEAST.RES, for case 5 is included at the end of the section.

Test Example 12 Input File

```
Test Example 12-5 :  Complex slope with nails and piles      26 May 2000
All nails and piles are activated.  PWPmin in silt layer = -100 kPa
*
* Date         Sign   Log of file modifications
* -----------  ----   ----------------------------------------------------
* 26 May 2000  cjfc   Original version, units used are : kN & m
* 21 Apr 2003  cjfc   Modifications for BEAST rev. 4
*

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1     IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   31     IDEFTO    ANALYSIS METHOD & TYPE, E.G. 31 = BEAST-2003 & EFF.STRESS
    0     NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
   15     NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0     SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.50 0.50          VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.50 0.50 0.00     VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0     ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    1     JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -2     IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    0     JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000   CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  0.000   CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
    8     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    1     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    3     NUMLAY    NUMBER OF HORIZONTAL LAYERS
    1     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
 -100.0      -10.0      40     1
    0.0      -10.0      40     1
   30.0        0.0      40     1
   54.0       24.0      40     1
   58.0       22.0      40     1
   68.0       22.0      40     1
   72.0       24.0      40     1
  200.0       24.0      40     0
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
    1       0.0       1
    2      26.0       2
    3      40.0       3
  TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
    1          1       54 -50      54  26      200 26
  0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

 ****************** MATERIAL PROPERTIES SECTION
    3     NUMMAT    NUMBER OF DIFFERENT MATERIALS
    0     NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
    0     NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
    0     CRACKZ    SURFACE OPEN CRACK DEPTH
    0     CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
  0.0     PHIREF    FRICTION ANGLE REFERENCE PRESSURE
 EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
  1    20.0    0.0    35.0     0       0       0.0     0      0     0     .001
  2    19.0    5.0    28.0     0       0       0.0     0      0     0     1.0
  3    18.0    0.0     0.0     0       0       0.0     0      0     0     .001
 TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
  1    20.0     1.00    1.00    1.00     0.0
  2    19.0     1.00    1.00    1.00     0.0
  3    18.0     1.00    1.00    1.00    75.0
 X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
 NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)
```

Test example no. : 12

```
 ****************** PORE-WATER-PRESSURES SECTION
     2      IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
     3      NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
     0      NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
   0.0      FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
   0.0      WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
  10.0      GAMWAT    FREE WATER UNIT WEIGHT
   0.0      GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
-100.0      PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
   1        0       2         0   40
                              0  400
   2       30       2        10   40
                              0  250
   3       54       2        24   40
                              0  100
  NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)

 ****************** LOAD SECTION
 1801       NUMPNT              NUMBER OF POINT (I.E. LINE) LOADS
    1       NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
  0.0       SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
 -100 100 XTOP1,XTOP2           STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
  1.0 1.0 FCTPNT,FCTSIG         POINT AND DISTRIBUTED LOAD FACTORS
  0.0 1.0 ACCXRT,ACCZRT         ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
  POINT    X-COORD   Z-COORD    X-FORCE   Z-FORCE
    1       10.0      -6.5        0.0      100.0
  STRIP      X1        X2       SIGZ1     SIGZ2      TAUX1     TAUX2
    1        15        25        50        50         0         0
 Nail X.hed Z.hed X.tip Z.tip C/C Diam Tens  Comp Dist Q.axl Q.lat Q.hed Miscl
  No.  (m)   (m)   (m)   (m)  (m)  (m) (kPa) (kPa) (m) (kN)  (kN)  (kN)  1-2-3
   1   32     2   22.5   5.2  2.0 .150   75    0   1.0  300    0   150   0 0 0
   2   34     4   24.5   7.2  2.0 .150   75    0   1.0  300    0   150   0 0 0
   3   36     6   26.5   9.2  2.0 .150   75    0   1.0  300    0   150   0 0 0
   4   38     8   28.5  11.2  2.0 .150   75    0   1.0  300    0   150   0 0 0
   5   40    10   30.5  13.2  2.0 .150   75    0   1.0  300    0   150   0 0 0
   6   42    12   32.5  15.2  2.0 .150   75    0   1.0  300    0   150   0 0 0
   7   44    14    25   20.4  2.0 .150   75    0   1.0  300    0   150   0 0 0
   8   46    16    27   22.4  2.0 .150   75    0   1.0  300    0   150   0 0 0
   9   48    18    29   24.4  2.0 .150   75    0   1.0  300    0   150   0 0 0
  10   50    20    31   26.4  2.0 .150   75    0   1.0  300    0   150   0 0 0
  11   52    22   42.5  25.2  2.0 .150   75    0   1.0  300    0   150   0 0 0
  12   20  -3.5    20   100   2.5 .500   75   75   0.0 11200  1065    0   0 0 0
  13   25  -2.0    25   100   2.5 .500   75   75   0.0 11200  1065    0   0 0 0
  14   30   0.0    30   100   2.5 .500   75   75   0.0 11200  1065    0   0 0 0
  15   35     5    35   100   2.5 .500   75   75   0.0 11200  1065    0   0 0 0
  16   40    10    40   100   2.5 .500   75   75   0.0 11200  1065    0   0 0 0
  17   45    15    45   100   2.5 .500   75   75   0.0 11200  1065    0   0 0 0
  18   50    20    50   100   2.5 .500   75   75   0.0 11200  1065    0   0 0 0

 **************** GIVEN SHEAR SURFACE
   0    0         SURFACE NUMBER , NUMBER OF POINTS ON SURFACE

End of Beast input file c:\cjfc\beast\data\testx12.05b
```

Test Example 12 Printed Results, File NF16, BEAST.RES

```
# BEAST  Output   Program Version = 21 Apr 2003    Time = 22 APR 2003  15:48:41

 Test Example 12-5 :  Complex slope with nails and piles      26 May 2000
 All nails and piles are activated.  PWPmin in silt layer = -100 kPa

 =====================================================  SAFETY FACTOR =   1.075

 SURFACE NO :   1     SUMMARY OF GEOMETRY AND STRESSES
 =====================================================  SOLUTION SCORE=   0.414

 SURFACE TYPE = CIRCLE          X-CENTER  Z-CENTER   RADIUS
                                 30.000   -39.000    75.717

 SOLUTION METHOD = BEAST-2003 / EFFECTIVE STRESS ANALYSIS

 SLICE     X1      Z1      Z2      WXT-FRC     P-STR      E2-STR     U2-STR    ROUGH   H2/Z23
           X2      Z4      Z3      WZT-FRC     S-STR      T2-STR     U3-STR            H3/L34

   1   -39.88  -10.00  -10.00   0.000E+00  3.609E+01  2.418E+01  0.000E+00  0.560  0.582
   1   -34.85   -9.98    0.00   5.047E+02  2.351E+01  8.826E+00  0.000E+00         0.500

   2   -34.85  -10.00  -10.00   1.435E-14  1.098E+02  4.316E+01  1.537E+01  0.561  0.330
   2   -29.91    0.00    7.25   1.327E+03  5.897E+01  1.546E+01  3.624E+01         0.500

   3   -29.91  -10.00  -10.00   4.685E-14  1.610E+02  5.437E+01  3.699E+01  0.568  0.290
   3   -24.98    7.25   13.00   1.936E+03  8.428E+01  1.846E+01  1.012E+02         0.500

   4   -24.98  -10.00  -10.00  -3.342E-14  2.154E+02  6.362E+01  6.650E+01  0.577  0.272
   4   -17.52   13.00   19.89   3.820E+03  1.112E+02  2.161E+01  1.644E+02         0.500

   5   -17.52  -10.00  -10.00   5.168E-14  2.677E+02  6.598E+01  8.096E+01  0.583  0.267
   5   -13.13   19.89   23.17   2.674E+03  1.371E+02  2.256E+01  2.153E+02         0.500

   6   -13.13  -10.00  -10.00   4.463E-14  3.054E+02  6.550E+01  9.420E+01  0.591  0.261
   6    -8.74   23.17   26.00   2.930E+03  1.557E+02  2.272E+01  2.459E+02         0.500

   7    -8.74  -10.00  -10.00  -2.792E-14  3.535E+02  7.858E+01  1.097E+02  0.569  0.205
   7    -2.61   26.00   29.30   4.440E+03  6.977E+01  2.961E+01  2.765E+02         0.500

   8    -2.61  -10.00   -8.38   2.848E-14  4.007E+02  1.083E+02  1.134E+02  0.561  0.195
   8     4.85   29.30   32.38   5.746E+03  6.977E+01  3.605E+01  3.000E+02         0.500

   9     4.85   -8.38   -5.90   3.941E-15  4.358E+02  1.426E+02  1.073E+02  0.554  0.204
   9    12.31   32.38   34.58   5.853E+03  6.977E+01  4.337E+01  2.902E+02         0.500

  10    12.31   -5.90   -3.41  -3.353E-14  4.738E+02  1.722E+02  9.815E+01  0.548  0.206
  10    19.77   34.58   36.00   5.863E+03  6.977E+01  4.959E+01  2.724E+02         0.500

  11    19.77   -3.41   -0.93  -7.926E+02  6.402E+01  1.679E+02  8.611E+01  0.546  0.260
  11    27.22   36.00   36.62   2.231E+03  6.977E+01  4.843E+01  2.477E+02         0.500

  12    27.22   -0.93    4.68  -3.963E+02  6.895E+02  1.989E+02  6.966E+01  0.545  0.353
  12    34.68   36.62   36.55   6.530E+03  6.977E+01  5.162E+01  2.101E+02         0.500

  13    34.68    4.68   12.14  -7.926E+02  7.549E+02  2.217E+02  5.314E+01  0.544  0.660
  13    42.14   36.55   35.70   6.375E+03  6.977E+01  5.615E+01  1.511E+02         0.500

  14    42.14   12.14   19.59  -3.963E+02  4.621E+02  2.836E+02  3.677E+01  0.550  1.278
WARNINGS: 1
  14    49.59   35.70   34.09   3.515E+03  6.977E+01  4.870E+01  1.071E+02         0.500

  15    49.59   19.59   22.47  -3.963E+02  2.629E+02  2.998E+02  2.014E+01  0.549  2.618
WARNINGS: 1
  15    57.05   34.09   31.70   2.059E+03  6.977E+01  5.551E+01  6.167E+01         0.500

  16    57.05   22.47   22.00  -5.350E-15  1.415E+02  2.791E+02  9.325E+00  0.556  4.899
WARNINGS: 1
  16    64.51   31.70   28.35   1.132E+03  6.977E+01  8.554E+01  3.764E+01         0.500

  17    64.51   22.00   22.37  -1.190E-15  1.463E+02  3.120E+02  3.471E+00  0.581  9.999
WARNINGS: 1
  17    68.74   28.35   26.00   4.253E+02  6.977E+01  1.181E+02  1.983E+01         0.500

  18    68.74   22.37   23.98  -1.570E-16  2.757E+02 -2.095E-10  0.000E+00  0.000  0.500
WARNINGS: 1
  18    71.96   26.00   23.99   1.171E+02  1.796E+02  1.568E-10  6.219E+00       -11.502
```

```
# BEAST  Output   Program Version = 21 Apr 2003    Time = 22 APR 2003  15:48:41

 Nail   Total   Active  Forces at shear surface   Slice   Failure mode
  no.   length  length    Axially   Laterally    intsctn

   1    10.024   0.000   0.000E+00  0.000E+00      00     No intersection
   2    10.024   0.000   0.000E+00  0.000E+00      00     No intersection
   3    10.024   0.000   0.000E+00  0.000E+00      00     No intersection

   4    10.024   0.000   0.000E+00  0.000E+00      00     No intersection
   5    10.024   0.000   0.000E+00  0.000E+00      00     No intersection
   6    10.024   0.000   0.000E+00  0.000E+00      00     No intersection

   7    20.049   0.000   0.000E+00  0.000E+00      00     No intersection
   8    20.049   0.000   0.000E+00  0.000E+00      00     No intersection
   9    20.049   0.000   0.000E+00  0.000E+00      00     No intersection

  10    20.049   0.000   0.000E+00  0.000E+00      00     No intersection
  11    10.024   0.000   0.000E+00  0.000E+00      00     No intersection
  12   103.500  39.529   4.332E+03  9.907E+02      11     Internal/Compression

  13   102.000  38.538   4.223E+03  9.907E+02      11     Internal/Compression
  14   100.000  36.717  -4.024E+03  9.907E+02      12     Internal/Tension
  15    95.000  31.538  -3.456E+03  9.907E+02      13     Internal/Tension

  16    90.000  26.029  -2.853E+03  9.907E+02      13     Internal/Tension
  17    85.000  20.184  -2.212E+03  9.907E+02      14     Internal/Tension
  18    80.000  13.989  -1.533E+03  9.907E+02      15     Internal/Tension

 THIS RUN WAS TERMINATED :  22 APR 2003  AT  15:48:41 HOURS

 TIME USED =     0 SECONDS
```

Test Example 12 Printed Results, File NF17, BEAST.PLT

```
# BEAST  Output   Program Version = 21 Apr 2003    Time = 22 APR 2003  15:48:41

 Test Example 12-5 :  Complex slope with nails and piles      26 May 2000
 All nails and piles are activated.  PWPmin in silt layer = -100 kPa

 NUMSRF  NTYP  NUMSLC  METHOD  IDEFTO  NNAILS  MISC1 MISC2 MISC3 MISC4 MISC5
    1      2     18      3       1      18      0     0     0     0     0
 SAFETY.FCT  SCORE  R-FACTOR   VALMSC1  VALMSC2  VALMSC3  VALMSC4  VALMSC5
   1.0750    0.414   1.000      0.000    0.000    0.000    0.000    0.000

   3.0000E+01 -3.9000E+01  7.5717E+01  0.0000E+00  0.0000E+00 STORE(1,2,3,4,5)
   0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 STORE(6,7,8,9,10)

 GEOMETRY AND INITIAL ROUGHNESS
 SLICE  X2          Z2          Z3          X5          Z5          R0
   0  -3.9883E+01 -1.0000E+01 -9.9820E+00
   1  -3.4845E+01 -1.0000E+01  0.0000E+00 -3.6528E+01 -6.6667E+00  5.0000E-01
   2  -2.9911E+01 -1.0000E+01  7.2481E+00 -3.2159E+01 -3.0273E+00  5.0000E-01
   3  -2.4977E+01 -1.0000E+01  1.2996E+01 -2.7326E+01  1.2953E-01  5.0000E-01
   4  -1.7520E+01 -1.0000E+01  1.9886E+01 -2.1086E+01  3.2955E+00  5.0000E-01
   5  -1.3129E+01 -1.0000E+01  2.3174E+01 -1.5286E+01  5.7792E+00  5.0000E-01
   6  -8.7391E+00 -1.0000E+01  2.6000E+01 -1.0904E+01  7.3030E+00  5.0000E-01
   7  -2.6055E+00 -1.0000E+01  2.9298E+01 -5.6276E+00  8.8365E+00  5.0000E-01
   8   4.8515E+00 -8.3828E+00  3.2379E+01  1.1457E+00  1.0831E+01  5.0000E-01
   9   1.2308E+01 -5.8972E+00  3.4579E+01  8.5756E+00  1.3168E+01  5.0000E-01
  10   1.9765E+01 -3.4115E+00  3.6004E+01  1.6020E+01  1.5314E+01  5.0000E-01
  11   2.7223E+01 -9.2583E-01  3.6617E+01  2.3464E+01  1.7065E+01  5.0000E-01
  12   3.4680E+01  4.6795E+00  3.6549E+01  3.0849E+01  1.9192E+01  5.0000E-01
  13   4.2137E+01  1.2137E+01  3.5700E+01  3.8222E+01  2.2184E+01  5.0000E-01
  14   4.9594E+01  1.9594E+01  3.4093E+01  4.5569E+01  2.5265E+01  5.0000E-01
  15   5.7051E+01  2.2475E+01  3.1698E+01  5.3046E+01  2.6956E+01  5.0000E-01
  16   6.4508E+01  2.2000E+01  2.8346E+01  6.0549E+01  2.6189E+01  5.0000E-01
  17   6.8739E+01  2.2370E+01  2.6000E+01  6.6431E+01  2.4724E+01  5.0000E-01
  18   7.1957E+01  2.3979E+01  2.3987E+01  6.9814E+01  2.4117E+01  0.0000E+00
```

Test example no. : 12

SOIL STRENGTHS AND PWP

SLICE	C2	C3	TAN2	TAN3	U2	U3
1	0.0000E+00	0.0000E+00	7.0021E-01	7.0021E-01	0.0000E+00	0.0000E+00
2	1.2500E+00	5.0000E+00	6.5808E-01	5.3171E-01	2.6507E+02	3.1776E+02
3	3.7500E+00	5.0000E+00	5.7383E-01	5.3171E-01	8.5053E+02	7.6683E+02
4	3.7500E+00	5.0000E+00	5.7383E-01	5.3171E-01	1.9874E+03	1.6692E+03
5	3.7500E+00	5.0000E+00	5.7383E-01	5.3171E-01	2.6859E+03	1.1808E+03
6	3.7500E+00	5.0000E+00	5.7383E-01	5.3171E-01	3.3912E+03	1.2838E+03
7	2.1250E+01	7.5000E+01	4.4091E-01	0.0000E+00	4.3109E+03	1.9254E+03
8	2.1250E+01	7.5000E+01	4.4091E-01	0.0000E+00	4.6219E+03	2.4207E+03
9	2.1250E+01	7.5000E+01	4.4091E-01	0.0000E+00	4.3420E+03	2.2561E+03
10	2.1250E+01	7.5000E+01	4.4091E-01	0.0000E+00	3.8685E+03	2.0681E+03
11	2.1250E+01	7.5000E+01	4.4091E-01	0.0000E+00	3.2328E+03	1.8533E+03
12	2.2500E+01	7.5000E+01	3.9878E-01	0.0000E+00	2.2201E+03	1.5665E+03
13	2.2500E+01	7.5000E+01	3.9878E-01	0.0000E+00	1.2521E+03	1.1343E+03
14	5.7500E+01	7.5000E+01	1.3293E-01	0.0000E+00	5.3318E+02	8.1718E+02
15	5.6250E+01	7.5000E+01	1.7505E-01	0.0000E+00	1.8579E+02	4.8302E+02
16	1.8750E+01	7.5000E+01	5.2516E-01	0.0000E+00	5.9175E+01	3.0772E+02
17	0.0000E+00	7.5000E+01	7.0021E-01	0.0000E+00	1.2603E+01	9.5941E+01
18	0.0000E+00	0.0000E+00	7.0021E-01	7.0021E-01	0.0000E+00	2.3603E+01

CALCULATED FORCES AND ROUGHNESS

SLICE	P	S	E2	T2	SS	R
1	4.0350E+02	2.6282E+02	2.4180E+02	8.8265E+01	0.0000E+00	5.6042E-01
2	9.6286E+02	5.1703E+02	7.4437E+02	2.6671E+02	0.0000E+00	5.6062E-01
3	1.2196E+03	6.3849E+02	1.2503E+03	4.2450E+02	0.0000E+00	5.6778E-01
4	2.1874E+03	1.1291E+03	1.9013E+03	6.4575E+02	0.0000E+00	5.7698E-01
5	1.4682E+03	7.5171E+02	2.1889E+03	7.4855E+02	0.0000E+00	5.8290E-01
6	1.5946E+03	8.1303E+02	2.3581E+03	8.1777E+02	0.0000E+00	5.9073E-01
7	2.4616E+03	4.8586E+02	3.0879E+03	1.1635E+03	0.0000E+00	5.6939E-01
8	3.2330E+03	5.6294E+02	4.4158E+03	1.4694E+03	0.0000E+00	5.6149E-01
9	3.3882E+03	5.4242E+02	5.7722E+03	1.7552E+03	0.0000E+00	5.5412E-01
10	3.5972E+03	5.2968E+02	6.7891E+03	1.9544E+03	0.0000E+00	5.4843E-01
11	4.7904E+02	5.2202E+02	6.3032E+03	1.8184E+03	0.0000E+00	5.4649E-01
12	5.1415E+03	5.2029E+02	6.3382E+03	1.6452E+03	0.0000E+00	5.4508E-01
13	5.6659E+03	5.2363E+02	5.2241E+03	1.3232E+03	0.0000E+00	5.4428E-01
14	3.5248E+03	5.3221E+02	4.1116E+03	7.0620E+02	0.0000E+00	5.5000E-01
15	2.0594E+03	5.4644E+02	2.7650E+03	5.1200E+02	0.0000E+00	5.4883E-01
16	1.1565E+03	5.7042E+02	1.7710E+03	5.4282E+02	0.0000E+00	5.5625E-01
17	7.0800E+02	3.3755E+02	1.1326E+03	4.2865E+02	0.0000E+00	5.8105E-01
18	1.0463E+03	6.8154E+02	-1.8661E-12	1.3967E-12	0.0000E+00	0.0000E+00

CENTER LOADS AND MOMENT ARMS

SLICE	WX+SNX	WZ+SNZ	WM+SNM	H2	H3	HS
1	0.0000E+00	5.0470E+02	0.0000E+00	5.8178E+00	5.5906E+00	0.0000E+00
2	-2.3999E+00	1.1477E+03	1.0150E+02	5.6940E+00	4.3841E+00	0.0000E+00
3	-3.6037E+00	1.4367E+03	5.6212E+01	6.6724E+00	3.7878E+00	0.0000E+00
4	-4.1024E+00	2.5941E+03	1.3256E+02	8.1224E+00	5.0763E+00	0.0000E+00
5	9.3227E+00	1.7286E+03	-3.4872E+01	8.8414E+00	2.7423E+00	0.0000E+00
6	-1.0417E+01	1.8501E+03	9.7507E+01	9.3798E+00	2.6107E+00	0.0000E+00
7	-7.9497E+00	2.7439E+03	9.2483E+01	8.0647E+00	3.4819E+00	0.0000E+00
8	6.1348E+02	3.5088E+03	3.8373E+03	7.9633E+00	4.0343E+00	0.0000E+00
9	9.1813E+02	3.6891E+03	5.2791E+03	8.2634E+00	3.8873E+00	0.0000E+00
10	8.6184E+02	3.8319E+03	4.7235E+03	8.1379E+00	3.7960E+00	0.0000E+00
11	-4.9936E+00	3.8417E+02	-1.3790E+04	9.7591E+00	3.7411E+00	0.0000E+00
12	6.0219E+02	4.9634E+03	-6.1689E+01	1.1240E+01	3.7287E+00	0.0000E+00
13	4.7073E+01	5.2483E+03	-5.7372E+03	1.5558E+01	3.7526E+00	0.0000E+00
14	1.5049E+02	2.7165E+03	-2.2914E+03	1.8533E+01	3.8141E+00	0.0000E+00
15	-1.9660E+02	1.5994E+03	-6.2353E+02	2.4149E+01	3.9161E+00	0.0000E+00
16	4.3979E-01	8.5175E+02	-1.2781E+01	3.1088E+01	4.0880E+00	0.0000E+00
17	5.9071E-02	3.4141E+02	-1.4098E+01	4.3745E+01	2.4191E+00	0.0000E+00
18	8.7676E-02	9.7104E+01	-1.5097E-01	4.4530E-03	-4.3655E+01	0.0000E+00

CENTRE LOADS (WX,WZ,WM) NEGLECTING SOIL NAILS AND THE NAIL LOADS (SNX,SNZ,SNM)

SLICE	WX	WZ	WM	SNX	SNZ	SNM
1	0.0000E+00	5.0470E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	-2.3999E+00	1.1477E+03	1.0150E+02	0.0000E+00	0.0000E+00	0.0000E+00
3	-3.6037E+00	1.4367E+03	5.6212E+01	0.0000E+00	0.0000E+00	0.0000E+00
4	-4.1024E+00	2.5941E+03	1.3256E+02	0.0000E+00	0.0000E+00	0.0000E+00
5	9.3227E+00	1.7286E+03	-3.4872E+01	0.0000E+00	0.0000E+00	0.0000E+00
6	-1.0417E+01	1.8501E+03	9.7507E+01	0.0000E+00	0.0000E+00	0.0000E+00
7	-7.9497E+00	2.7439E+03	9.2483E+01	0.0000E+00	0.0000E+00	0.0000E+00
8	6.1348E+02	3.5088E+03	3.8373E+03	0.0000E+00	0.0000E+00	0.0000E+00
9	9.1813E+02	3.6891E+03	5.2791E+03	0.0000E+00	0.0000E+00	0.0000E+00
10	8.6184E+02	3.8319E+03	4.7235E+03	0.0000E+00	0.0000E+00	0.0000E+00
11	7.8758E+02	3.8064E+03	4.8491E+03	-7.9257E+02	-3.4222E+03	-1.8639E+04
12	9.9848E+02	3.3538E+03	5.5157E+03	-3.9628E+02	1.6095E+03	-5.5774E+03
13	8.3964E+02	2.7247E+03	3.0125E+03	-7.9257E+02	2.5236E+03	-8.7497E+03
14	5.4677E+02	1.8318E+03	1.1358E+03	-3.9628E+02	8.8479E+02	-3.4272E+03
15	1.9968E+02	9.8617E+02	2.9602E+02	-3.9628E+02	6.1325E+02	-9.1955E+02
16	4.3979E-01	8.5175E+02	-1.2781E+01	0.0000E+00	0.0000E+00	0.0000E+00
17	5.9071E-02	3.4141E+02	-1.4098E+01	0.0000E+00	0.0000E+00	0.0000E+00
18	8.7676E-02	9.7104E+01	-1.5097E-01	0.0000E+00	0.0000E+00	0.0000E+00

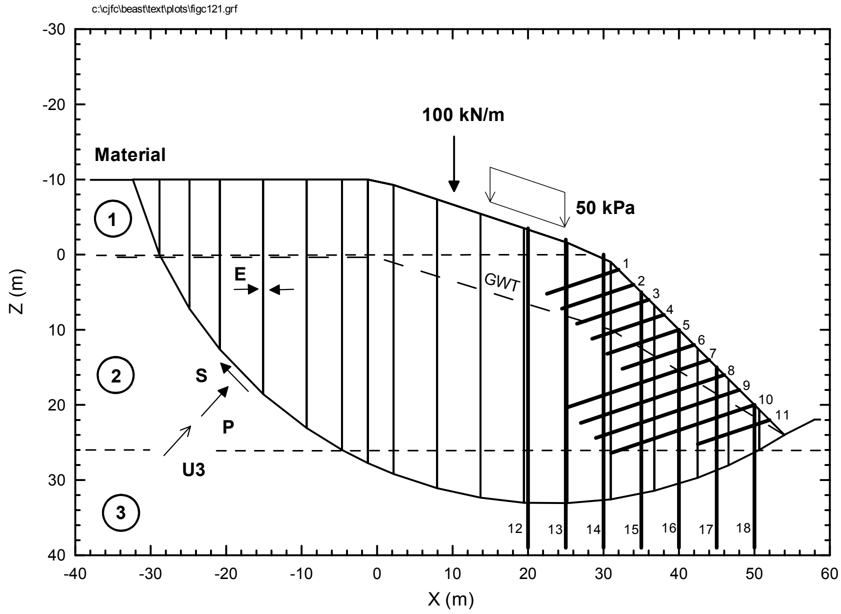
SOIL NAIL GEOMETRY VALUES

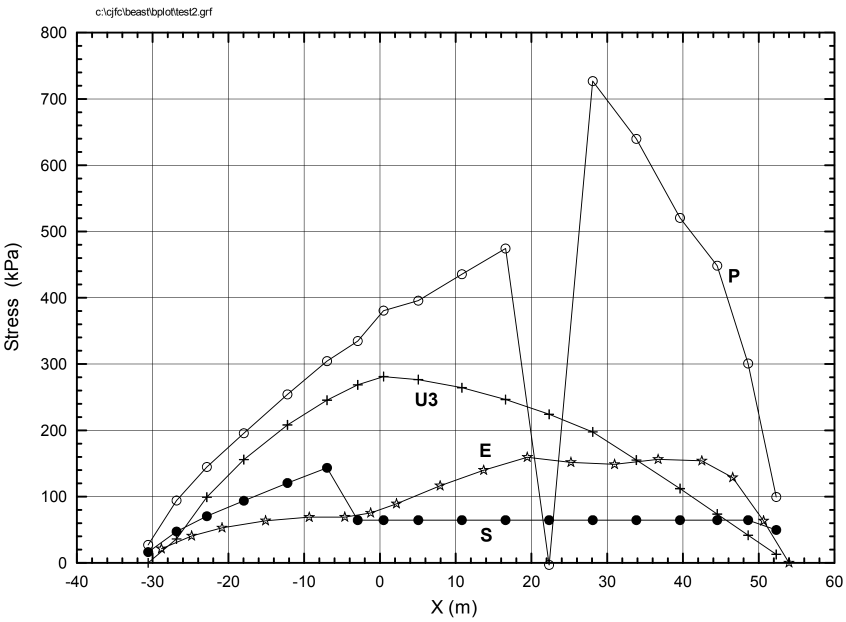
NAIL	X.HEAD	Z.HEAD	X.TIP	Z.TIP	C/C.DIST	ACTIVE.LNGTH
1	3.2000E+01	2.0000E+00	2.2500E+01	5.2000E+00	2.0000E+00	0.0000E+00
2	3.4000E+01	4.0000E+00	2.4500E+01	7.2000E+00	2.0000E+00	0.0000E+00
3	3.6000E+01	6.0000E+00	2.6500E+01	9.2000E+00	2.0000E+00	0.0000E+00
4	3.8000E+01	8.0000E+00	2.8500E+01	1.1200E+01	2.0000E+00	0.0000E+00
5	4.0000E+01	1.0000E+01	3.0500E+01	1.3200E+01	2.0000E+00	0.0000E+00
6	4.2000E+01	1.2000E+01	3.2500E+01	1.5200E+01	2.0000E+00	0.0000E+00
7	4.4000E+01	1.4000E+01	2.5000E+01	2.0400E+01	2.0000E+00	0.0000E+00
8	4.6000E+01	1.6000E+01	2.7000E+01	2.2400E+01	2.0000E+00	0.0000E+00
9	4.8000E+01	1.8000E+01	2.9000E+01	2.4400E+01	2.0000E+00	0.0000E+00
10	5.0000E+01	2.0000E+01	3.1000E+01	2.6400E+01	2.0000E+00	0.0000E+00
11	5.2000E+01	2.2000E+01	4.2500E+01	2.5200E+01	2.0000E+00	0.0000E+00
12	2.0000E+01	-3.5000E+00	2.0000E+01	1.0000E+02	2.5000E+00	3.9529E+01
13	2.5000E+01	-2.0000E+00	2.5000E+01	1.0000E+02	2.5000E+00	3.8538E+01
14	3.0000E+01	0.0000E+00	3.0000E+01	1.0000E+02	2.5000E+00	3.6717E+01
15	3.5000E+01	5.0000E+00	3.5000E+01	1.0000E+02	2.5000E+00	3.1538E+01
16	4.0000E+01	1.0000E+01	4.0000E+01	1.0000E+02	2.5000E+00	2.6029E+01
17	4.5000E+01	1.5000E+01	4.5000E+01	1.0000E+02	2.5000E+00	2.0184E+01
18	5.0000E+01	2.0000E+01	5.0000E+01	1.0000E+02	2.5000E+00	1.3989E+01

SOIL NAIL FORCES AT SHEAR SURFACE INTERSECTION (UNITS=FORCE) AND MISC VALUES

NAIL	FRC.AXIAL	FRC.LATRL	MISC.1	MISC.2	MISC.3	FAIL.MODE
1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
6	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
7	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
9	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
11	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0
12	4.3321E+03	9.9071E+02	0.0000E+00	0.0000E+00	0.0000E+00	4
13	4.2235E+03	9.9071E+02	0.0000E+00	0.0000E+00	0.0000E+00	4
14	-4.0238E+03	9.9071E+02	0.0000E+00	0.0000E+00	0.0000E+00	3
15	-3.4563E+03	9.9071E+02	0.0000E+00	0.0000E+00	0.0000E+00	3
16	-2.8526E+03	9.9071E+02	0.0000E+00	0.0000E+00	0.0000E+00	3
17	-2.2120E+03	9.9071E+02	0.0000E+00	0.0000E+00	0.0000E+00	3
18	-1.5331E+03	9.9071E+02	0.0000E+00	0.0000E+00	0.0000E+00	3

Test example no. : 12





Soil material no.	Total unit weight kN/m^2	c' kPa	φ' degrees	s_u kPa
1	20	0	35	0
2	19	5	28	0
3	18	0	0	75

Figure C.12.1

Test example 12, slope with soil nails (1-11) and piles (12-18)

TEST EXAMPLE : 13

Slopes Analysed by Different Authors

These test cases were initially presented by Fredlund & Krahn (1977). The same cases have later been analysed by a number of different authors, using different methods :

Fredlund & Krahn (1977)	Limiting equilibrium, comparison of different methods and coputer codes.
Baker (1980)	Limiting equilibrium, determination of the critical shear surface.
Leshchinsky & Huang (1992)	Limiting equilibrium
Kim et al (2002)	Limit analysis, finite element based

The slope considered is shown on Figure C.13.1. Fredlund & Krahn (1977) analysed six different cases :

Case	Weak soil layer	Pore-water-pressures
1	Not present	No PWPs
2	Include	No PWPs
3	Not present	r_u = 0.25
4	Include	r_u = 0.25
5	Not present	Given piez. line (GWT)
6	Include	Given piez. line (GWT)

The shear surface considered by Fredlund & Krahn (1977) was the circle shown on Figure C.13.1. This circle has its centre at XC = 36.6m and ZC = 7.2 m, and a radius of 24.4 m. For cases 2, 4 and 6 the shear surface is non-circular since it follows the thin weak layer.

Input data to BEAST for case 6 is included on Figure C.13.2.

Results obtained by the different authors, and by BEAST, for the surface considered by Fredlund & Krahn (1977) are compared in Table C.13.1. There is a good agreement between the different solutions. Excluding the Fredlund & Krahn (1977) solutions for Janbu's method, the maximum difference between the solutions for any of the six cases is 6 %.

Table C.13.2 compares the critical shear surfaces found by Baker (1980) and by BEAST-2003 to the FE based solutions presented by Kim et al (2002). The same good agreement is found for the critical shear surfaces as well. The limiting equilibrium solutions are within 5 %. For cases 2 and 6 the limiting equilibrium solutions fall between the FE lower and upper bound results. For case 4 both Baker (1980) and BEAST give safety factors that are lower than the FE lower bound. The reason for this anomaly has not been investigated further.

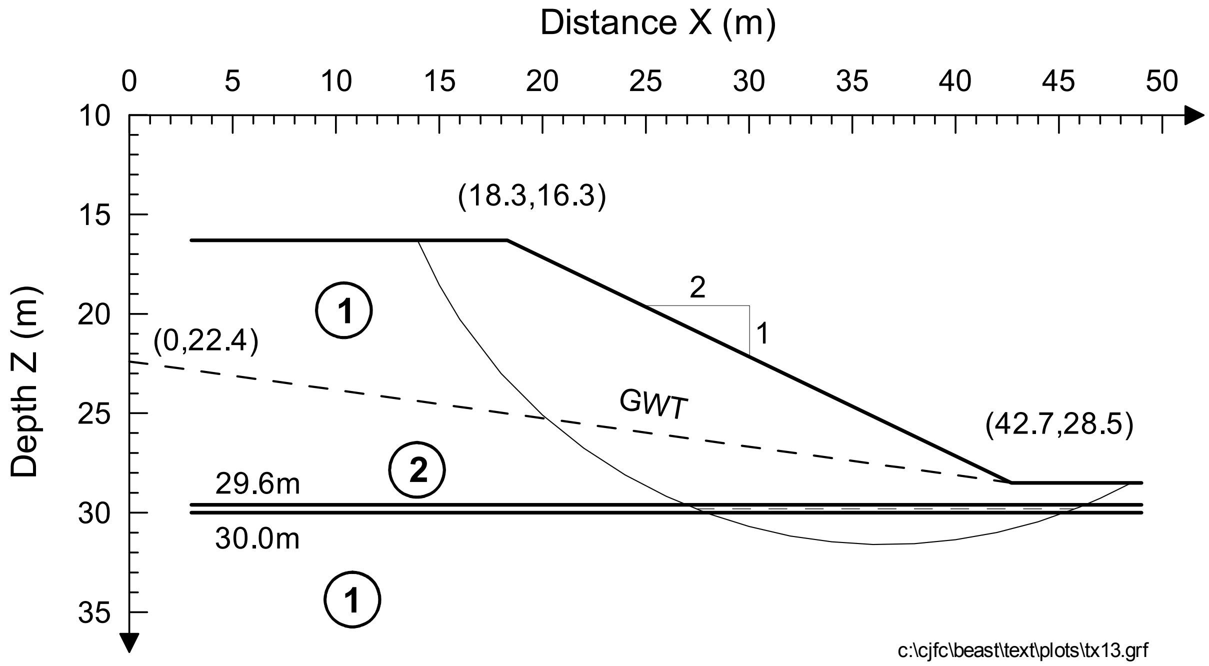
*Table C.13.1 : Comparison of limiting equilibrium solutions,
shear surfaces considered by Fredlund & Krahn (1977).
Values shown are the calculated safety factors.*

Case	Fredlund & Krahn (1977)				Baker	Lesh. et al (1992)		BEAST, Revision 4			
no.	Bishop s	Spencer	Janbu	M&P	(1980)	σ_o = 0	σ_o = -79	1988-2002	Bishop s	Bishop m	B 2003
1	2.080	2.073	2.008	2.076	2.08	2.08	2.05	2.074	2.074	2.084	2.084
2	1.377	1.372	1.432	1.378	1.38	1.31	1.33	1.368	1.368	1.355	1.355
3	1.766	1.761	1.708	1.765	1.75	1.77	1.74	1.758	1.758	1.767	1.767
4	1.124	1.118	1.162	1.124	1.10	1.07	1.08	1.107	1.107	1.098	1.098
5	1.834	1.830	1.776	1.833	1.83	1.84	1.81	1.808	1.808	1.817	1.817
6	1.248	1.245	1.298	1.250	1.23	1.18	1.20	1.207	1.207	1.199	1.199

*Table C.13.2 : Comparison of solutions, critical shear surfaces.
Values shown are the calculated safety factors.*

Case	Baker	Kim et al (2002)			BEAST
no.	(1980)	Spencer's method	FE lower bound	FE upper bound	2003 method
1	1.98				2.02
2	1.29	1.34	1.25	1.37	1.30
3	1.68				1.73
4	1.01	-	1.07	1.16	1.03
5	1.77				1.80
6	1.15	1.21	1.10	1.23	1.15

Test example no. : 13



Soil material no.	Total unit weight kN/m^3	c' kPa	φ' degrees
1	18.8	28.7	20.0
2	18.8	0.0	10.0

Figure C.13.1

Geometry and soil properties for test example no. 13, Fredlund & Krahn (1977)

Test example no. : 13

```
Test Example 13-6 :  Fredlund and Krahn (1977) Slope  Case 06     19 Mar 2003
Slope with thin weak layer, PWPs from GWT, non-circular shear surface

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1     IDTYP     SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
   31     IDEFTO    ANALYSIS TYPE : 1=EFFCTV STRESS 2=TOTAL STRESS 3=COMBINED
    0     NUMGEN    NUMBER OF GENERAL SHEAR SURFACES
   20     NUMSLC    NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
  0.0     SIDSHR    SIDE SHEAR FACTOR (0.0=PLANE STRAIN , 2.0/LENGTH=MAX)
 0.00 0.00          VALUES FOR H3-ASSMPTN (H3(X)=H31+(H32-H31)/XTOT*X)
 0.00 0.00 1.00     VALUES FOR R-ASSMPTN  (R(X)=R1+(R2-R1)/XTOT*X+H(X)/HMAX*R3)
    0     ITENSP    ALLOW P-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     ITENSE    ALLOW E-FORCE TENSION IN SCORE CALCULATION (0=NO 1=YES)
    0     JPRINT    TRACE PRINT CODE (0=NON 1=LIM 2=TRACE 3=DETLD TRACE)
   -2     IPRTTP    FILE NF16 PRINT TYPE FOR SLICE OUTPUT (1=FORCES 2=STRESSES)
    0     JPLOT     CODE FOR PLOT(S) ON NF16 (0=NO 1=YES 2=+PWP/SU0 3=+MESH)
  0.000   CRTFRC    CONVERGENCE CRITERION , FORCES   (DEFAULT=SUM(FZ)/1.0E4)
  0.000   CRTSCR    CONVERGENCE CRITERION , SOLUTION SCORE
C  MISC1  MISC2  MISC3  MISC4  MISC5   VAL1  VAL2  VAL3  VAL4  VAL5
     0      0      0      0      0      0.0   0.0   0.0   0.0   0.0
C MISC1=1 flags that BEAST is allowed to change the shear surface exit angle

 ****************** GEOMETRY SECTION
    4     NUMXLN    NUMBER OF X-LINES WITH SURFACE, ROCK AND ELEMENT SPECS
    1     NUMELZ    NUMBER OF ELEMENTS IN Z-DIRECTION
    2     NUMLAY    NUMBER OF HORIZONTAL LAYERS
    0     NUMTRI    NUMBER OF MATERIAL I.D. TRIANGLES
  X-VALUE  Z-SURFACE  Z-ROCK  NUMBER OF X-ELEMENTS TO NEXT X-LINE
 -100.0       16.3     30.0    1
   18.3       16.3     30.0    1
   42.7       28.5     30.0    1
  100.0       28.5     30.0    0
 00 00 00  0.0 0.0  NP1,NP2,NSTEP,ZN1,ZN2  NODE NEW Z , NP2=MAX TERMINATES
 00 00 00   0       NE1,NE2,NSTEP,MAT      ELEMENT MATRL , NE2=MAX TERMINATES
  LAYER  Z-BOTTOM  MATERIAL-I.D.
    1      29.6        1
    2      30.0        2
  TRIANGLE  MATERIAL   X1  Z1      X2  Z2      X3  Z3
  0 0 0   XWALL,HWALL,RWALL   WALL SPECIFICATIONS (LOCATION,HEIGHT,ROUGHNESS)

 ****************** MATERIAL PROPERTIES SECTION
    2     NUMMAT    NUMBER OF DIFFERENT MATERIALS
    0     NUMXSU    NUMBER OF VERTICAL X-LINES WITH GIVEN SU-VALUES
    0     NODSU     NUMBER OF MESH NODAL POINTS WITH GIVEN SU-VALUES
    0     CRACKZ    SURFACE OPEN CRACK DEPTH
    0     CRACKW    WATER DEPTH IN OPEN SURFACE CRACK
  0.0     PHIREF    FRICTION ANGLE REFERENCE PRESSURE
 EFFECTIVE STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  COHSN  PHIANG  PHIRED  PWPMAT  RU-MAT  B-FACT K-NOT B-SIG2 D-FCT
  1    18.8   28.7    20.0     0       0      0.0     0      0     0     1.0
  2    18.8    0.0    10.0     0       0      0.0     0      0     0     1.0
 TOTAL STRESS ANALYSIS STRENGTH PARAMETERS (ALWAYS INCLUDE , ZERO OK)
 MAT  GAMTOT  SUA/SU0 SUD/SU0 SUP/SU0  SU0-MAT  (A:ACTIVE D:DIRECT P:PASSIVE)
  1    18.8     1.00    1.00    1.00     0.0
  2    18.8     1.00    1.00    1.00     0.0
 X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : SU0-VALUES
 NODE   SU0   (IF ALL NODES, SKIP NODE NUMBERS : SU0(1),SU0(2),...)

 ****************** PORE-WATER-PRESSURES SECTION
    2     IDPWP     PWP INDICATOR (1=HYDROSTATIC  2=NON-HYDROSTATIC)
    2     NUMXPW    NUMBER OF VERTICAL X-LINES WITH GIVEN PWP WITH DEPTH
    0     NODPWP    NUMBER OF MESH NODAL POINTS WITH GIVEN PWP
   0.0    FCTNOD    FACTOR ON PWP-VALUES GIVEN AT NODAL POINTS
   0.0    WATERZ    HORIZONTAL WATER TABLE Z-LEVEL
```

Figure C.13.2

BEAST input data for test example 13, case 6

Test example no. : 13

```
  10.0    GAMWAT    FREE WATER UNIT WEIGHT
   0.0    GAMPWP    PORE WATER UNIT WEIGHT (=GAMWAT IF HYDROSTATIC)
   0.0    PWPMIN    MINIMUM ALLOWABLE PWP (CAPILLARY TENSION)
X-LINE  X-COORD  Z-POINTS   LINE 1 : Z-VALUES / LINE 2 : PWP-VALUES
   1       0.0      3       18.3  22.4  122.4
                               0     0   1000
   2      42.7      2       28.5  128.5
                               0   1000
  NODE  PWP-VALUE  (IF ALL NODES , SKIP NODE NUMBERS : PWP(1),PWP(2),...)
 ****************** LOAD SECTION
    0     NUMPNT              NUMBER OF POINT LOADS & SOIL NAILS
    0     NUMSIG              NUMBER OF SURFACE DISTRIBUTED LOADS
   0.0    SIGTOP              UNIFORM INITIAL VERTICAL STRESS AT SURFACE
 -100 100 XTOP1,XTOP2         STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
  1.0 1.0 FCTPNT,FCTSIG       POINT AND DISTRIBUTED LOAD FACTORS
  0.0 1.0 ACCXRT,ACCZRT       ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
  POINT   X-COORD   Z-COORD   X-FORCE   Z-FORCE
  STRIP     X1       X2       SIGZ1     SIGZ2     TAUX1     TAUX2
End of Beast input file c:\cjfc\beast\data\testx13.006
```

Figure C.13.2 cont.

BEAST input data for test example 13, case 6

Appendix D

Soil Nail Procedures

Contents Page

D.1 Introduction

In April 2000 it was decided to include a “soil nail” option in program BEAST. This option allows the strengthening effects of soil nails to be included in the BEAST solution. In the following the term “soil nail” is used for any single structural element (e.g. a soil nail, a pile or an earth anchor) that may interact with the surrounding soils.

The concept of soil nailing, and some example applications, are described by Gässler (1988), Jewell (1990), FHA (1991), Aabøe (1992) and Vaslestad (1996).

D.2 Soil/Structure Interaction Analysis

Figure D.2.1 shows a slope with a trial circular shear surface, a pile A and two soil nails B and C. As the soil body tends to rotate, it is observed that the vertical pile A goes into compression, soil nail B just follows the rigid body soil movement, and soil nail C goes into tension.

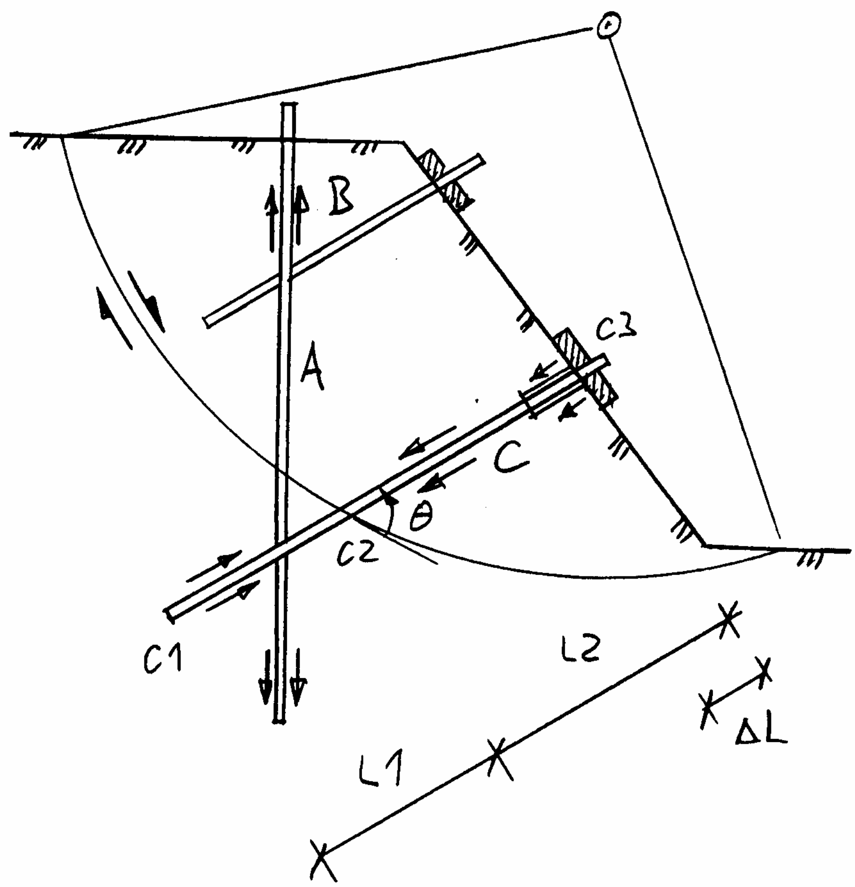


Figure D.2.1

Slope reinforced by a pile A and by soil nails B and C.

It will be assumed that only soil nails that intersect the shear surface has an effect upon the stability. Soil nail B on the figure can thus be neglected for the shear surface shown.

The input data (see Section D.6 below) for a soil nail includes geometry, skin friction nail/soil, bearing capacity of the anchor plate at the slope face, and the axial and lateral structural capacities of the nail itself. When nail C is subjected to tensile axial loading, it can fail by three different mechanisms :

1. The embedded part C1-C2 is being pulled out, the nail follows the rotation of the soil body.

2. The embedded part C1-C2 has a capacity higher than C2-C3. The nail itself is stationary while the soil volume rotates past section C2-C3 of the nail.

3. The weak link is the axial structural capacity of the nail itself. The steel yields at point C2 before full nail/soil skin friction is mobilised.

The actual failure mode will be the one of these three with the lowest capacity. The axial failure force that acts at point C2 can therefore be calculated for each nail for a given shear surface.

This force is then uniformly distributed in nine points along the nail part C2-C3. If the force at C2 exceeds the skin friction capacity on C2-C3, the remaining part is carried at the anchor plate at point C3.

In the example shown on Figure D.2.1 soil nail C goes into tension. Whether a nail develops tension or compression is governed by the angle θ between the shear surface and the nail axis. As this angle increases and becomes higher than 90°, the soil nail axial force goes from tension to compression. For simplicity, BEAST assumes that a nail has either full tension or full compression, with $\theta = 90°$ taken as the dividing point.

The soil nail shear (i.e. lateral) force at point C2 will be governed by both soil and nail strength. This force can be calculated as described in Section D.4 in case the lateral soil nail capacity shall be included in the analysis.

For a safety factor of 1.0 we therefore know all the forces, and their positions, delivered from a given soil nail to the soil volume located above the shear surface considered. BEAST forms the sum of these forces in the X and Z directions, and the corresponding moments, at the centre of each slice, point 5 on Figure 3.6.1 in the main text. These known soil nail forces and moments at the centre of each slice, valid for SF = 1.0, will be referred to as :

Force in X-direction	SNWX(i)
Force in Z-direction	SNWZ(i)
Corresponding moment at slice centre, point 5	SNWM(i)

where "i" is the slice number. These forces are included in the governing equations for the system of slices as described in Section D.5 below.

D.3 Axial Soil Nail Capacity

For a given soil nail we know the following values, see Figure D.2.1 :

L1 =	Length from the nail tip to the shear surface
L2 =	Length from the nail head to the shear surface
d =	Soil nail diameter
τ =	Soil nail skin friction

ΔL = Distance from the nail head to where the soil/nail skin friction starts

Qhead = Bearing capacity of the plate/beam at the nail head

Qstruct = Soil nail axial structural capacity

Two values are read as input for the skin friction, τ in tension and τ in compression. If the soil nail capacity to carry compressive loading shall not be included, for example as a result of low buckling resistance, the skin friction τ in compression should be given as zero.

Assuming that ΔL is smaller than L2, we get the following capacities in tension :

$$Qoutside = \pi \cdot d \cdot \tau \cdot L1 \quad \text{(D.3.1)}$$

$$Qinside = \pi \cdot d \cdot \tau \cdot (L2 - \Delta L) + Qhead \quad \text{(D.3.2)}$$

The axial capacity of the nail in tension is then given by :

$$Qaxial = MIN (Qoutside , Qinside , Qstruct) \quad \text{(D.3.3)}$$

For loading in compression the expressions are the same, except that Qhead is taken as zero. In case ΔL is higher than L2, L1 is replaced by L1+L2-ΔL, and L2-ΔL is set to zero.

D.4 Lateral Soil Nail Capacity

For small diameter soil nails and anchors the lateral capacity will often be negligible. However, for the sake of generality, the lateral capacity of the soil nails are read as input by BEAST, and included in the numerical solutions. For large diameter soil nails and piles the lateral load bearing capacity may be important.

Figure D.4.1 shows a tubular pipe element that is fully embedded in soil. This pipe is intersected by a shear surface. After a certain displacement along the shear surface, the pipe develops two yield hinges located at a distance “h” from the shear plane. We want to determine the shear force Q that corresponds to a fully developed plastic yield moment My in the pipe.

The lateral stress q acting against a pipe embedded in clay may be taken as :

$$q.clay = 9 \cdot s_u \quad \text{(D.4.1)}$$

where s_u is the clay undrained shear strength. For a frictional material the API RP2A (1993) recommendations for laterally loaded piles in sand lead to the following approximate expression :

$$q.sand \approx 100 \cdot \tan^3 (\varphi') \cdot \gamma' \cdot z \quad \text{(D.4.2)}$$

where φ' is the angle of internal friction, γ' is the average effective soil unit weight and z is the depth below the soil surface.

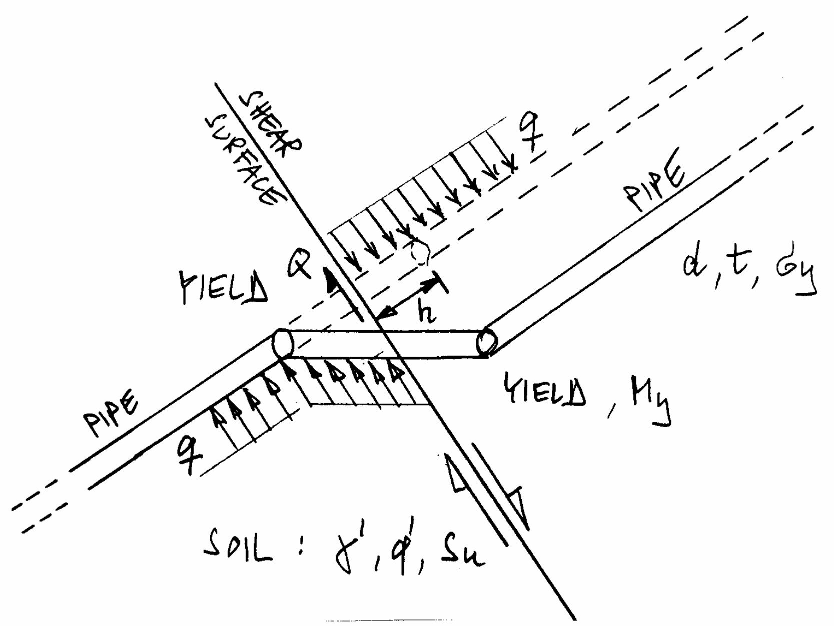


Figure D.4.1

Lateral yielding of a pipe embedded in soil

For a circular cross section the plastic yield moment My is given by :

$$My = \sigma_y \cdot \{d^3 - (d-2t)^3\} / 6 \qquad (D.4.3)$$

where d is the pipe outer diameter, t is the wall thickness and σ_y is the wall yield stress.

The shear force must be zero where the pipe yields. For reasons of symmetry the pipe bending moment at the shear surface must be zero. Equilibrium therefore requires that :

$$Q = q \cdot d \cdot h \qquad (D.4.4)$$

$$My = Q \cdot h - 0.5 \cdot q \cdot d \cdot h^2 \qquad (D.4.5)$$

which leads to :

$$Q = (2 \cdot My \cdot q \cdot d)^{0.5} \qquad (D.4.6)$$

This shear capacity Q is read as input by BEAST. If the soil nail lateral capacity shall be included in the analysis, the value Q must be calculated manually by the user from the above formulae.

It is the responsibility of the user to ensure that the lateral capacity given is compatible with the axial loading and the axial capacity. As an example, the structural lateral capacity cannot be mobilised if the soil nail already carries an axial force close to the structural capacity of the nail.

D.5 Modified Governing Equations

The governing equations for a single slice with known or assumed safety factor, but without soil nail loads, are presented in Section 3.6 of the main text. When soil nail loads are included, these equations are modified as follows.

In equation (3.6.1), $\sum$ x-forces = 0.0, the term WX shall be replaced by WX + SNWX / SF.

In equation (3.6.2), $\sum$ z-forces = 0.0, the term WZ shall be replaced by WZ + SNWZ / SF.

In equation (3.6.3), $\sum$ moments = 0.0, the same WX and WZ changes shall be included, and WM shall be replaced by WM + SNWM / SF.

The same modifications apply for the coefficients C12, C23 and C31; equations (3.6.9), (3.6.13) and (3.6.14) respectively.

D.6 Soil Nails Input Data

Test example no. 12 in Appendix C is a slope with soil nails and vertical piles. Part of this input file is reproduced below, followed by an explanation of the different values in the soil nails table heading. Maximum allowed number of soil nails is 75.

```
Test Example 12 :  Complex slope with nails and piles      26 May 2000
All nails and piles are activated.  PWPmin in silt layer = -100 kPa

 ****************** CONTROL SECTION
  1.0 1.0 CONFRC,CONLTH   CONVERTION FACTORS ON FORCES AND LENGTHS
  1.0 1.0 FCTSUC,FCTTAN   MATERIAL FACTORS ON SU,C AND TAN(PHI)
    1     IDTYP      SOLUTION TYPE (1=STAB/BEARING 2=EARTH PRESS)
    1     IDEFTO     ANALYSIS TYPE : 1=EFFCTV STRESS 2=TOTAL STRESS 3=COMBINED
    0     NUMGEN     NUMBER OF GENERAL SHEAR SURFACES
   15     NUMSLC     NUMBER OF SLICES (ZERO OK FOR GENERAL SURFACES)
.............

 ****************** LOAD SECTION
 1801     NUMPNT               NUMBER OF POINT (I.E. LINE) LOADS
    1     NUMSIG               NUMBER OF SURFACE DISTRIBUTED LOADS
   0.0    SIGTOP               UNIFORM INITIAL VERTICAL STRESS AT SURFACE
 -100 100 XTOP1,XTOP2          STRESS 'SIGTOP' ACTS FROM XTOP1 TO XTOP2
  1.0 1.0 FCTPNT,FCTSIG        POINT AND DISTRIBUTED LOAD FACTORS
  0.0 1.0 ACCXRT,ACCZRT        ACCELERATION RATIOS IN X- AND Z-DIRECTIONS
  POINT   X-COORD   Z-COORD    X-FORCE   Z-FORCE
    1      10.0      -6.5        0.0      100.0
  STRIP     X1        X2         SIGZ1     SIGZ2     TAUX1     TAUX2
    1       15        25          50        50         0         0
 Nail X.hed Z.hed X.tip Z.tip C/C Diam Tens  Comp Dist Q.axl  Q.lat Q.hed Miscl
  No.  (m)   (m)   (m)   (m)  (m)  (m) (kPa) (kPa) (m) (kN)   (kN)  (kN)  1-2-3
   1   32     2   22.5   5.2  2.0 .150   75    0   1.0  300     0    150   0 0 0
   2   34     4   24.5   7.2  2.0 .150   75    0   1.0  300     0    150   0 0 0
   3   36     6   26.5   9.2  2.0 .150   75    0   1.0  300     0    150   0 0 0
   4   38     8   28.5  11.2  2.0 .150   75    0   1.0  300     0    150   0 0 0
   5   40    10   30.5  13.2  2.0 .150   75    0   1.0  300     0    150   0 0 0
   6   42    12   32.5  15.2  2.0 .150   75    0   1.0  300     0    150   0 0 0
   7   44    14    25   20.4  2.0 .150   75    0   1.0  300     0    150   0 0 0
   8   46    16    27   22.4  2.0 .150   75    0   1.0  300     0    150   0 0 0
   9   48    18    29   24.4  2.0 .150   75    0   1.0  300     0    150   0 0 0
  10   50    20    31   26.4  2.0 .150   75    0   1.0  300     0    150   0 0 0
  11   52    22   42.5  25.2  2.0 .150   75    0   1.0  300     0    150   0 0 0
  12   20  -3.5    20   100   2.5 .500   75   75   0.0 11200  1065    0    0 0 0
  13   25  -2.0    25   100   2.5 .500   75   75   0.0 11200  1065    0    0 0 0
  14   30   0.0    30   100   2.5 .500   75   75   0.0 11200  1065    0    0 0 0
  15   35     5    35   100   2.5 .500   75   75   0.0 11200  1065    0    0 0 0
  16   40    10    40   100   2.5 .500   75   75   0.0 11200  1065    0    0 0 0
  17   45    15    45   100   2.5 .500   75   75   0.0 11200  1065    0    0 0 0
  18   50    20    50   100   2.5 .500   75   75   0.0 11200  1065    0    0 0 0

 **************** GIVEN SHEAR SURFACE
   0    0          SURFACE NUMBER , NUMBER OF POINTS ON SURFACE

End of Beast input file c:\cjfc\beast\data\testx12.001
```

The presence of soil nails in this data set is flagged by NUMPNT = 1801 read on line 0088. This number is interpreted by BEAST to mean that the model includes 18 soil nails and 01 point loads. The soil nail values given in the table on lines 0098 to 0117 have the following meaning :

X.hed, Z.hed	Soil nail head X and Z coordinates
X.tip, Z.tip	Soil nail tip X and Z coordinates
C/C	Centre-to-centre distance between the nails in the Y direction
Diam	Outer diameter of the soil nail
Tens	Unit skin friction in tension
Comp	Unit skin friction in compression
Dist	Distance from the nail head to the point where the skin friction starts, ΔL on Figure D.2.1.
Q.axl	Soil nail structural strength axially
Q.lat	Soil nail structural strength laterally
Q.hed	Ultimate force carried at the nail head (by a plate or a beam), this force is governed by the bearing capacity of the soils at the slope face.
MISCL	Miscellaneous values. MISCL(1) = -1 is interpreted to mean that this nail shall be de-activated, i.e. all capacities are multiplied by zero. The two other MISCL values are at present not used for any purpose.

D.7 Soil Nails Calculated Results

The presence of active soil nails within the soil body considered will change the calculated safety factor and the calculated forces acting upon the slices. When soil nails have been specified, the printed output files NF16, BEAST.RES, and NF17, BEAST.PLT, will include results for the soil nails as well.

The values printed to file NF16 include :

* The total length of the nail, L1+L2
* The active length of the nail, L1 or L2-ΔL
* Axial and lateral forces at point C2, see Figure D.2.1
* Slice number where the nail intersects the shear surface
* Failure mode explanation

The values printed to file NF17 include :

* Nail head and tip coordinates
* Nail centre-to-centre distance in the Y-direction
* Nail active length, L1 or L2-ΔL
* Axial and lateral forces at point C2
* Three miscellaneous values, see Section D.6 above
* A soil nail failure mode code :

  0 Non-active soil nail
  1 External failure in tension
  2 External failure in compression
  3 Internal failure in tension
  4 Internal failure in compression
  5 Structural axial yielding of the soil nail

The terms “external” and “internal” refer to whether the soil/nail skin friction failure takes place outside the sliding body, or within the sliding body itself.

D.8 References

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"Review of Theoretical Models for Soil Nailing."
Performance of reinforced structures, International reinforced soil conference,
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Appendix E

Solution Procedures

Contents Page

E1 Introduction

This appendix presents the details of the different solution methods that can be used by revision 4 of the BEAST program. Revision 4 allows the user to choose between five different methods :

* Force equilibrium with given values of the interslice roughness R
* The method used by earlier BEAST revisions, referred to as BEAST 1988-2002
* Bishop's simplified method, Bishop (1955)
* Bishop modified method, see Section E6 below.
* BEAST 2003, see Section E7 below

Which solution method to be used by BEAST is determined by the value of the input parameter IDEFTO read from the file BEAST.INP as shown in the below table.

Table E1.1

Solution types and solution methods in BEAST revision 4.

The parameter IDEFTO in the BEAST input file may have one of the 15 values listed, and is used to set the value of METHOD and the revised value for IDEFTO.

Solution method parameter METHOD	Solution type parameter IDEFTO		
	1	2	3
	Eff. stress	Tot. stress	Combined
-1 Force equilibrium	-1	-2	-3
0 BEAST 1988-2002	1	2	3
1 Bishop Simplified	11	12	13
2 Bishop modified	21	22	23
3 BEAST 2003	31	32	33

E2 System and Notation

Figure E2.1 shows a single slice with the co-ordinate system and the notation that will be used in the following.

E1 = Effective normal force at face 1 (left face)

T1 = Shear force at face 1

E2 = Effective normal force at face 2 (right face)

T2 = Shear force at face 2

P = Effective normal force at face 3, the slice bottom

S = Shear force at the slice bottom

WX = Given horizontal force at the slice centre

WZ = Given vertical force at the slice centre

WM = Given moment at the slice centre

SS = Side shear force (to include an approximate 3D effect)

All forces are positive when acting in the direction shown on Figure E2.1. Pore-water-pressure forces acting against the faces 1, 2 and 3 are included in the known loads WX, WZ and WM. Piles and soil-nail forces give another set of (WX,WZ,WM) loads not shown on the figure for clarity reasons.

The point (XC,ZC) indicated on Figure E2.1 would be the circle centre for a circular shear surface. For non-circular surfaces this point is determined as the centre of a circle that pass through the start, middle and end points of the shear surface. (XC,ZC) is used as a convenient point for summation of stabilising and driving moments. However, any point could be used for this purpose.

The position of the normal forces is given in terms of :

H1 = Distance from E1 to corner 4
H2 = Distance from E2 to corner 3
H3 = Distance from P to corner 3

The co-ordinates of the slice centre point 5 is determined as the slice centre-of-gravity. The side shear force SS is assumed to go through the point :

$$X(SS) = XPS = X5 \qquad (E2.1)$$
$$Z(SS) = 0.5 \cdot (ZPS + Z5) \qquad (E2.2)$$
$$ZPS = Z3 - (Z3-Z4) \cdot (X3-XPS) / (X3-X4) \qquad (E2.3)$$

where (XPS,ZPS) is the intersection between the P-force and the slice bottom.

Other values used in the following include :

A, B = Scaling factors on P-forces, see Figure E4.1

C2, C3 = Cohesion at slice faces 2 and 3

C11, C12, ... = Constants

L23 = Distance from slice corner point 2 to 3

L34 = Distance from slice corner point 3 to 4

R = Slice interface roughness value, see equation (E3.4)

SF = Safety factor

β = Slope of shear surface at slice bottom

$\varphi 2$, $\varphi 3$ = Angle of internal friction at slice faces 2 and 3

λ = Scaling factor on slice interface roughness given as input

E3 Force Equilibrium Solution

Force equilibrium in the X-direction :

$$E1 + WX - E2 + P \cdot \sin(\beta) - (S + SS) \cdot \cos(\beta) = 0.0 \qquad (E3.1)$$

Force equilibrium in the Z-direction :

$$T1 + WZ - T2 - P \cdot \cos(\beta) - (S + SS) \cdot \sin(\beta) = 0.0 \qquad (E3.2)$$

Fully mobilised shear strength at slice face 3 :

$$S = (C3 \cdot L34 + P \cdot \tan(\varphi 3)) / SF \qquad (E3.3)$$

Mobilised shear strength at face 2 :

$$T2 = R \cdot (C2 \cdot L23 + E2 \cdot \tan(\varphi 2)) / SF \qquad (E3.4)$$

Introducing the shear strength equations into the force equilibrium equations leads to :

$$\text{Sum X :} \quad P \cdot C11 - E2 = C12 \qquad (E3.5)$$

$$\text{Sum Z :} \quad P \cdot C21 + R \cdot (E2 \cdot \tan(\varphi 2) / SF + C22) = C23 \qquad (E3.6)$$

where

$$C11 = \sin(\beta) - \tan(\varphi 3) \cdot \cos(\beta) / SF \qquad (E3.7)$$

$$C12 = -E1 - WX + SS \cdot \cos(\beta) / SF + C3 \cdot L34 \cdot \cos(\beta) / SF \qquad (E3.8)$$

$$C21 = \cos(\beta) + \tan(\varphi 3) \cdot \sin(\beta) / SF \qquad (E3.9)$$

$$C22 = C2 \cdot L23 / SF \qquad (E3.10)$$

$$C23 = T1 + WZ - SS \cdot \sin(\beta) / SF - C3 \cdot L34 \cdot \sin(\beta) / SF \qquad (E3.11)$$

This system is solved by an iterative procedure where different safety factors (SF) are tried until the calculated forces E2 and T2 are zero at the last slice. Some care is needed in order to secure convergence, see Section 3.7 and Figure 3.7.1 of the main text.

The solution obtained only include the slice forces, not the position H2 of the interslice effective force E2. A solution score value can therefore not be calculated, and the score value for force equilibrium solutions is set to 6.666.

E4 BEAST 1988-2002 Solution

For an assumed set of interslice roughness values R the equations in Section E3 can be used to find the safety factor that leads to force equilibrium in both the X and the Z directions. With known P-forces (called P_o-forces below) one can determine a modified set of P-forces that satisfy both global force and moment equilibrium. The procedure used by BEAST is illustrated on Figure E4.1.

We have the three unknowns A, B and SF which can be determined from the three global equilibrium equations for the system of slices :

$\sum$ X-forces = 0.0

$\sum$ Z-forces = 0.0

$\sum$ Moments = 0.0

The rather lengthy equations are not included here. They are established by subroutine MOMEQL and solved by subroutine SOLABC using a trial-and-error procedure. These equations end up being of the type shown below.

$$C11 \cdot A + C12 \cdot B + C13/SF + C14 \cdot A/SF + C15 \cdot B/SF + C16 = 0.0 \qquad (E4.1)$$

$$C21 \cdot A + C22 \cdot B + C23/SF + C24 \cdot A/SF + C25 \cdot B/SF + C26 = 0.0 \qquad (E4.2)$$

$$C31 \cdot A + C32 \cdot B + C33/SF + C34 \cdot A/SF + C35 \cdot B/SF + C36 = 0.0 \qquad (E4.3)$$

Having found a solution, the corresponding score value can then be calculated as described in Section 3.9 of the main text. Another set of interslice R-factors may then be tried to generate another set of P_o-forces, another complete solution, and the corresponding score value. The final solution can then be selected based upon the SF and the score values. The BEAST 1988-2002 method selects the solution with the lowest score. If several solutions with zero score were found, the zero score solution with the highest safety factor is taken as the final solution.

E5 Bishop Simplified Solution

The description of this method is given in Bishop (1955) and in most text books on foundation engineering. This method is the one described by Janbu et al (1956), page 24. The method only satisfies vertical force equilibrium for each slice, as well as moment equilibrium for the entire system of slices.

Reference is made to Figure E2.1 which shows the slice force notation that will be used in the following.

Force equilibrium in the Z-direction :

$$T1 + WZ - T2 - P \cdot \cos(\beta) - (S+SS) \cdot \sin(\beta) = 0.0 \qquad (E5.1)$$

Fully mobilised shear stress at face 3 :

$$S = (C3 \cdot L34 + P \cdot \tan(\varphi 3)) / SF \qquad (E5.2)$$

Introducing (E5.2) into (E5.1) leads to :

$$P \cdot C11 = T1 - T2 + WZ - C12 \qquad (E5.3)$$

where

$$C11 = \cos(\beta) + \tan(\varphi 3) \cdot \sin(\beta) / SF \qquad (E5.4)$$

$$C12 = (C3 \cdot L34 + SS) \cdot \sin(\beta) / SF \qquad (E5.5)$$

For an assumed value of the safety factor SF the value of P can be calculated from (E5.3) if it is assumed that T1 = T2. With known P-force the corresponding S-force is found from (E5.2).

The moment equilibrium of the system of slices may be expressed by (E5.6). For simplicity the terms that include soil nail and side shear forces are not shown.

$$\sum (S \cdot SF_{asm} \cdot Arm_{S\text{-}force}) / SF_{next} + \sum (P \cdot Arm_{P\text{-}force}) + \sum M5 = 0.0 \tag{E5.6}$$

which leads to :

$$SF_{next} = - \sum (S \cdot SF_{asm} \cdot Arm_{S\text{-}force}) / (\sum (P \cdot Arm_{P\text{-}force}) + \sum M5) \tag{E5.7}$$

where

SF_{next} = Safety factor for the next iteration
SF_{asm} = Safety factor assumed to find P- and S-forces
$Arm_{S\text{-}force}$ = S-force moment arm w.r.t. the selected centre
$Arm_{P\text{-}force}$ = P-force moment arm w.r.t. the selected centre
M5 = Moment due to loads WX, WZ and WM

The solution reached by this procedure is incomplete in the sense that the E-forces and T-forces are not known. These forces could be calculated from equations (E3.1) and (E3.2) since P and S are known. However, E2 and T2 would be different from zero at the end of the last slice. The score therefore cannot be calculated for this solution, and the score value is set to 8.888 for the Bishop simplified method.

E6 Bishop Modified Solution

The Bishop simplified solution described above includes the calculated P-forces against the bottom of the slices. These forces may therefore be used as P_o-forces in the procedure shown on Figure E4.1, and a modified solution generated, that satisfies all equilibrium conditions. Since this is a complete solution, the score value can be calculated.

E7 BEAST 2003 Solution

This method is an extension of the two methods described in Sections E5 and E6. When calculating the P- and S-forces the assumption T1 = T2 (Bishop simplified) is not being made. Instead force equilibrium in both X and Z directions is considered with an assumed interslice roughness taken as :

$$R = \lambda \cdot R_o \tag{E7.1}$$

where R_o is the interslice roughness value given as input and λ is a scaling factor taken as 0.0, 0.1, 0.2, 0.3, ... , 1.0. This results in 11 solutions with different R assumptions.

With assumed R-values and safety factor SF the equations (E3.5) and E3.6) may be used to calculate the P-forces :

$$\sum X = 0.0 \qquad P \cdot C11 - E2 = C12 \tag{E7.2}$$

$$\sum Z = 0.0 \qquad P \cdot C21 + R \cdot (E2 \cdot \tan(\varphi 2) / SF + C22) = C23 \tag{E7.3}$$

where C11 to C23 are defined in Section E3. Eliminating E2 from these two equations leads to :

$$P \cdot (C21 + R \cdot C11 \cdot \tan(\varphi 2) / SF) = C23 + R \cdot (C12 \cdot \tan(\varphi 2) / SF - C22) \tag{E7.4}$$

from which P is calculated. The S-force is then calculated from (E3.3). With known P- and S-forces at the slice bottom, the next SF assumption is calculated from the global moment equilibrium requirement as explained in Section E5.

This leads to a set of P_o-forces that can be used to find a complete solution as described in Section E6 for the Bishop modified method. Since this solution is complete, the score value can be calculated. The process is then repeated with the next λ value, and at the end we have 11 complete solutions with known safety factor and score value. The BEAST 2003 method then uses the same approach as BEAST 1988-2002 to select the "best" solution, see Section E4.

The difference between the BEAST 1988-2002 method and the BEAST 2003 method is thus the way the P_o-forces are generated. The old procedure uses force equilibrium solutions, where as the new procedure uses a combination of force and moment equilibrium.

E8 Combined Analysis Procedure

The equilibrium equations shown above, e.g. (E3.3), include the soil strengths C3 and φ3. For the combined analysis the strength parameters to be used are the ones that lead to the lowest shear force S. This cannot be determined in advance, since the P-force is not known.

Before solving the equilibrium equations BEAST therefore needs to assume if the undrained shear strength (s_u3) or the effective stress parameters (C3 and φ3) leads to the lowest shear force S. After a solution has been found, the program checks the correctness of the assumption made for all slices, with the present value of the P-force, and carries out another iteration if needed.

E9 References

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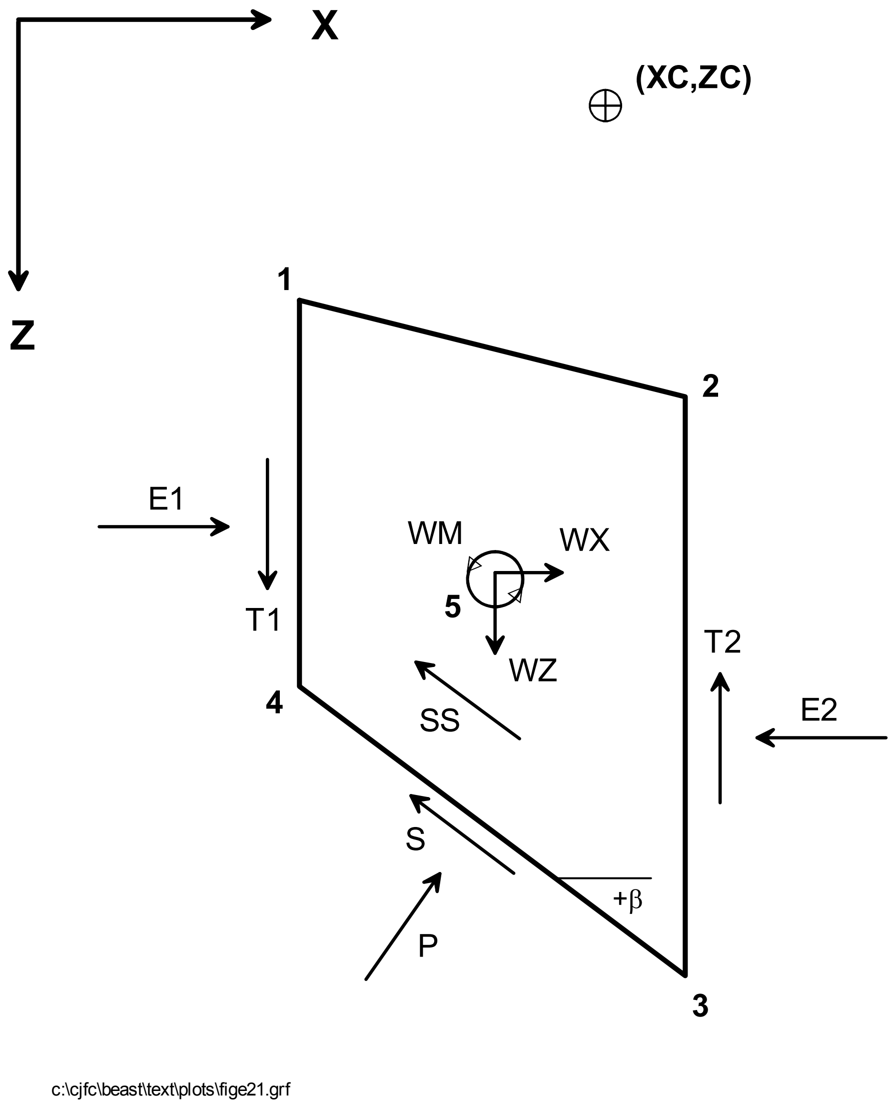
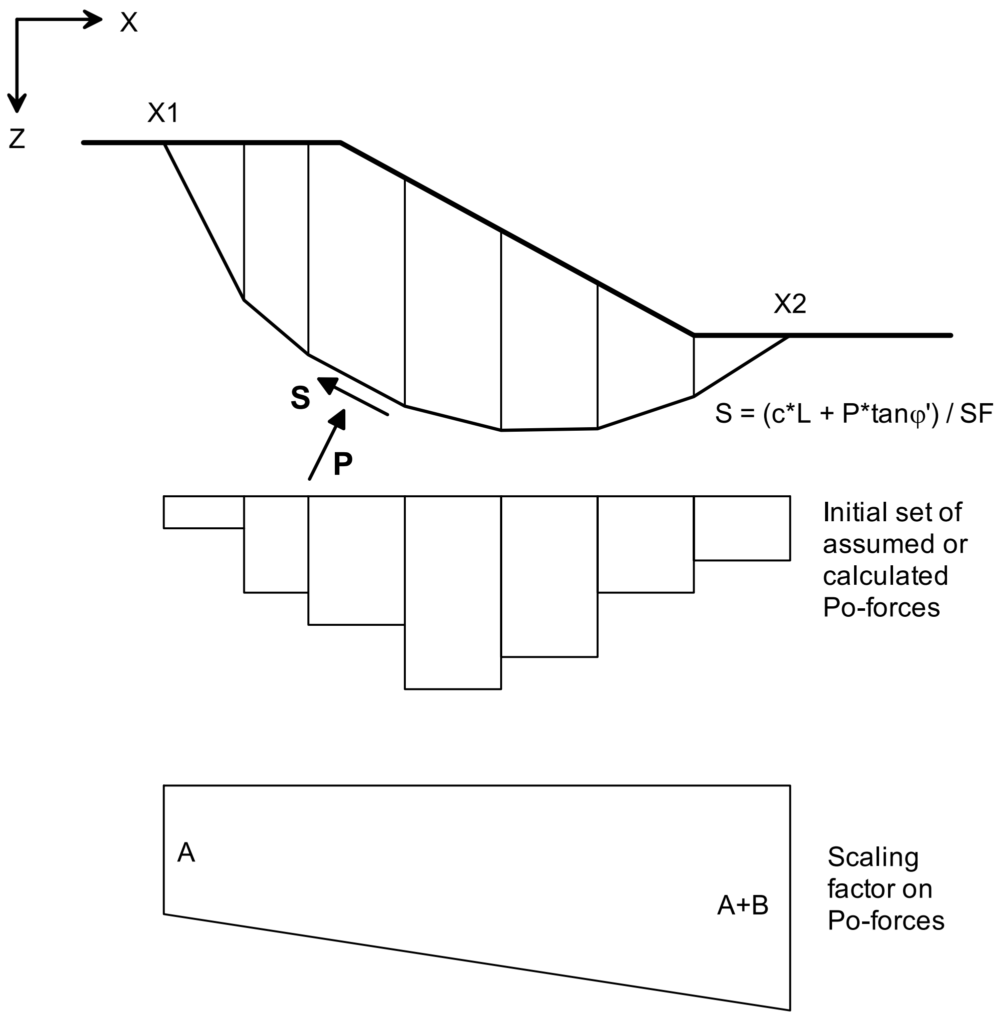


Figure E2.1

Single slice with the forces acting. E1, E2 and P are effective forces.

Pore-water-forces are included in the known loads WX, WZ and WM.



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$$P(x) = P_o(x) \cdot f(x)$$

$$f(x) = A \text{ for } X = X1$$

$$f(x) = A{+}B \text{ for } X = X2$$

The unknown values A, B and SF can be found from the 3 global equilibrium equations

Figure E4.1

Procedure used by BEAST to find a solution that satisfies both force and moment equilibrium