APPENDIC (C):U.K DCP V.3.1 PROCEDURE

Start up

This chapter describes how to run UK DCP 3.1 and introduces the Project Manager.

3.1 Run UK DCP 3.1

UK DCP 3.1 can be run by either clicking a desktop icon or through the Programs menu on the Start button. After a brief Flash screen (Figure 3.1), the Main window will open with a Welcome box (Figure 3.2). The Welcome box allows a new or existing project to be opened and also contains a list of the most recently used projects. The same options are available in the File menu at the top of the main window.

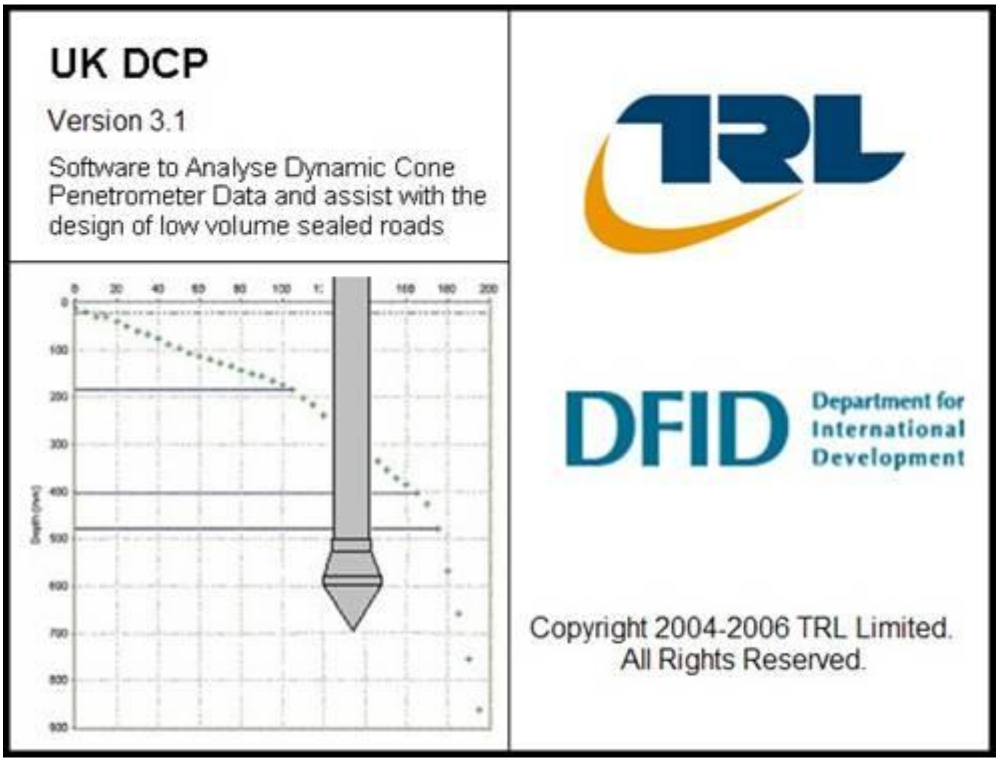

Figure 3.1 Flash Screen

Figure 3.2 Welcome box

3.1.1 Start a new project

Click *New Project* in the Welcome box or in the File menu at the top of the main window. This will generate a Save New Project As box. Give a name to the new project, select a folder in which to save it and click *Save*. The project will be automatically given a .ukdcp file extension and saved in the selected folder. An empty Project Manager box (Figure 3.3) will open for the new project with its name at the top. Since only one project can be open within UK DCP 3.1 at any time, if a project is currently open and a new project is named and saved, a message will be generated seeking confirmation that the current project should be closed. If *Yes* is clicked, the current project will be closed and a new project opened.

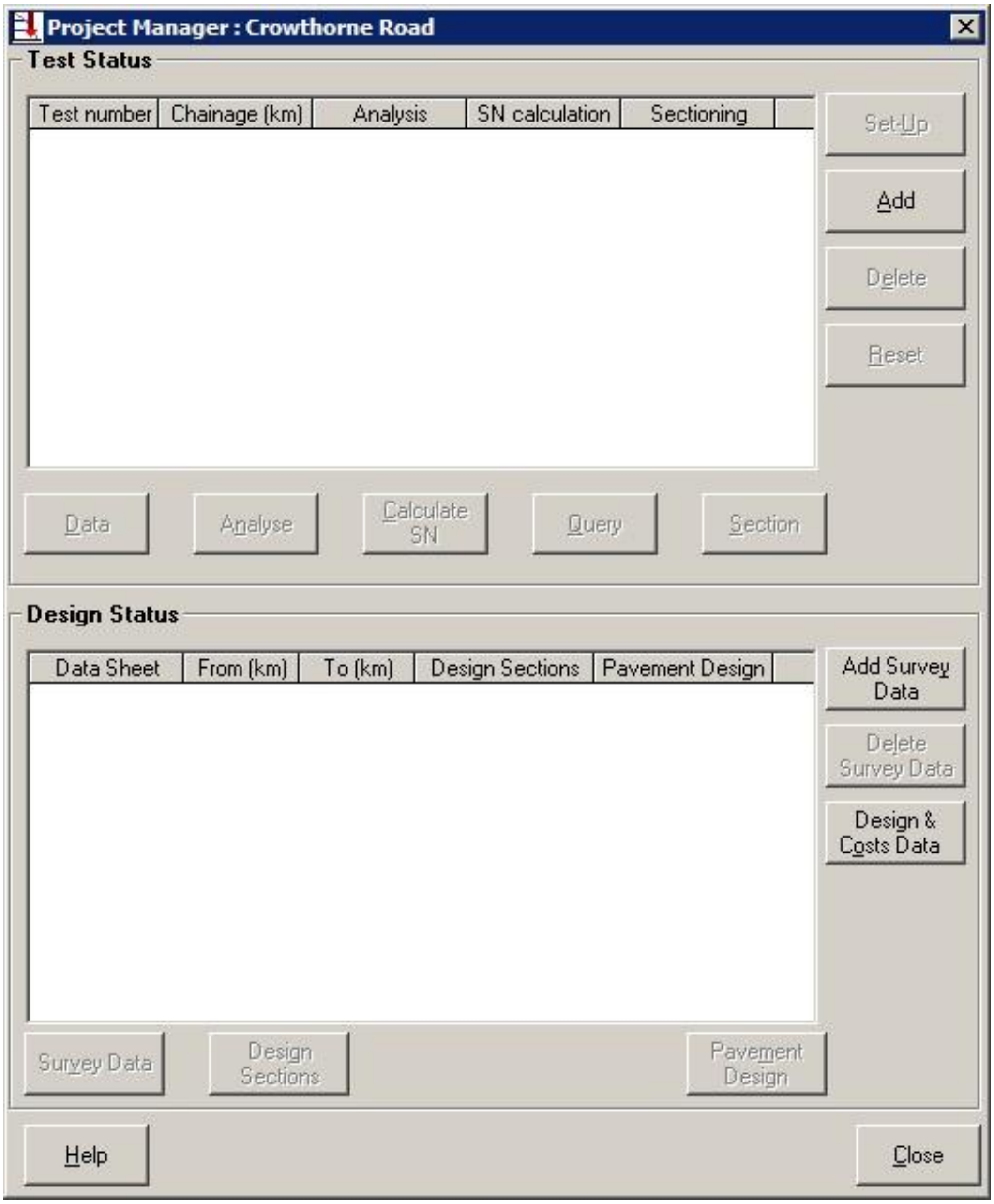

Figure 3.3 Project Manager (without test data)

3.1.2 Open an existing project

Click *Open Existing Project* in the Welcome box or *Open Project* in the File menu at the top of the main window. This will generate an Open Existing Project box in which the file of the required project can be found and selected. Highlight the file and click *Open*. A Project Manager filled with the existing data and analysis will open (Figure 3.4) shows a Project Manager of a project whose DCP data has been fully analysed). Alternatively, double-click on the required file in the Recent Files list in the Welcome box or in the File menu and the Project Manager will open. Since only one project can be open within UK DCP 3.1 at any time, if a project is currently open and an existing project is selected, a message will be generated seeking confirmation that the current project should be closed. If *Yes* is clicked, the current project will be closed and the selected project opened.

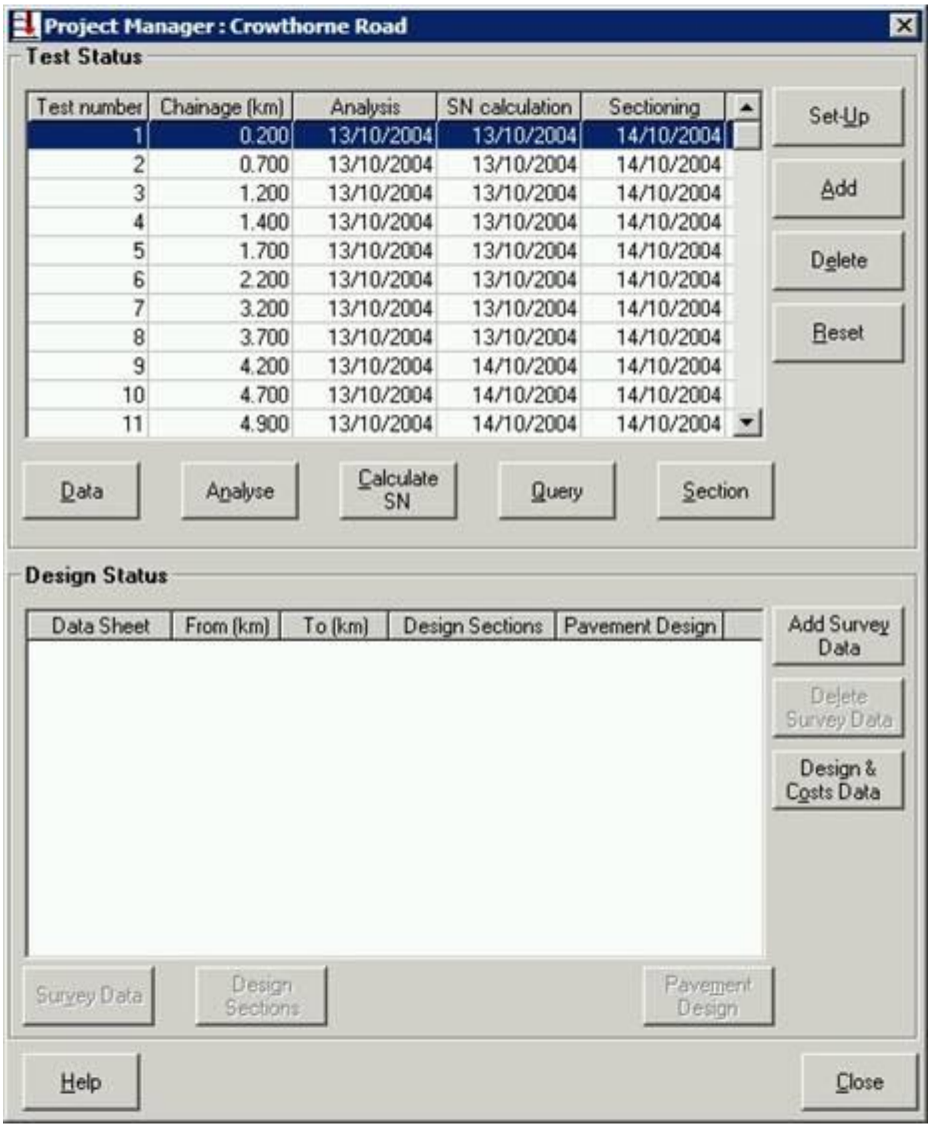

Figure 3.4 Project Manager (with test data and completed analysis)

3.1.3 Closing a project and exiting UK DCP 3.1.

Only one project can be run by UK DCP 3.1 at any time. To close a project, click *Close* in the Project Manager. A box will be generated seeking confirmation. Click *Yes* to close the project. To exit UK DCP 3.1, click *Exit* in the File menu at the top of the main window. A box will be generated seeking confirmation. Click *Yes* to exit.

3.2 Project Manager

The Project Manager has two panels: Test Status and Design Status. The Test Status panel is used to analyse DCP data, including penetration data input, layer analysis and strength calculation. The Design Status panel is used to design low volume sealed roads, including survey and cost data input, design section analysis and design production. Both panels are described below.

There are two buttons in the Project Manager common to the analysis and the design functions.

Help	Open this manual on the screen at the appropriate section.
Close	Close the project. UK DCP 3.1 remains open so that another project can be opened and analysed. A warning message is generated. Click *Yes* to continue.

3.2.1 Test Status

The Test Status panel is used to analyse DCP data, including penetration data input, layer analysis and strength calculation. Each row in the table in the Test Status panel (shown completed in Figure 3.4) represents one penetration test and shows the progress that has been made in analysing that data. The table has five columns.

Test number	Tests are automatically numbered in chainage order from 1 upwards. If more than one test is carried out at the same chainage, they are ordered according to their location (carriageway; shoulder; verge; lay-by / other – see 4.2 below). If more than one test is carried out at the same chainage in the carriageway, they are ordered according to their lane number and offset. If more than one test is carried out at the same chainage off the carriageway, they are ordered according to their offset. There is no limit to the number of tests that can be entered in a single project. If a test is added out of sequence or deleted, the numbering is automatically corrected.
Chainage (km)	The chainage at which the test was carried out, measured in kilometres.
Analysis	The date when the test data was analysed to identify layers. The cell is blank if the data has not yet been analysed.
SN calculation	The date when the Structural Numbers of the pavement layers were calculated. The cell is blank if these have not yet been calculated.

Sectioning	The date when DCP Sections were determined for the project. The cell is blank if the project has not yet been sectioned.

There are nine buttons in the Test Status panel associated with DCP data input and analysis. Warning messages are generated in response to *Delete* and *Reset*. In each case, click *Yes* to continue with the operation.

Set-Up	Record, review or edit information about how a selected test was carried out, analysed and displayed. This button is inactive if tests are being reviewed, edited or analysed.
Add	Input data from a new test into the Test Status table.
Delete	Delete a selected test from the Test Status table. This button is inactive if tests are being reviewed, edited or analysed.
Reset	Remove the layer analysis, Structural Number calculation and DCP Sections from all tests in the project.
Data	Review or edit the details of a selected test.
Analyse	Identify layers from the data of a selected test.
Calculate SN	Calculate the Structural Numbers of the pavement of a selected test. This button is inactive if layers have not yet been identified from the test data.
Query	Graphically present the strengths and layer thicknesses along the length of an entire project. This button is inactive unless Structural Numbers have been calculated for six or more tests in the project.
Section	Divide a project into DCP Sections according to a selection of strength and layer thickness parameters. This button is inactive unless Structural Numbers have been calculated for six or more tests in the project.

3.2.2 Design Status

The Design Status panel is used to design low volume sealed roads, including survey and cost data input, division into Design Sections and design production. Each row in the table in the Design Status panel (shown completed in Figure 3.5) represents the survey data from a single Data Sheet and shows the progress that has been made in producing the design. The use of the Design Status panel and the design process are described in Chapters 9 to 11.

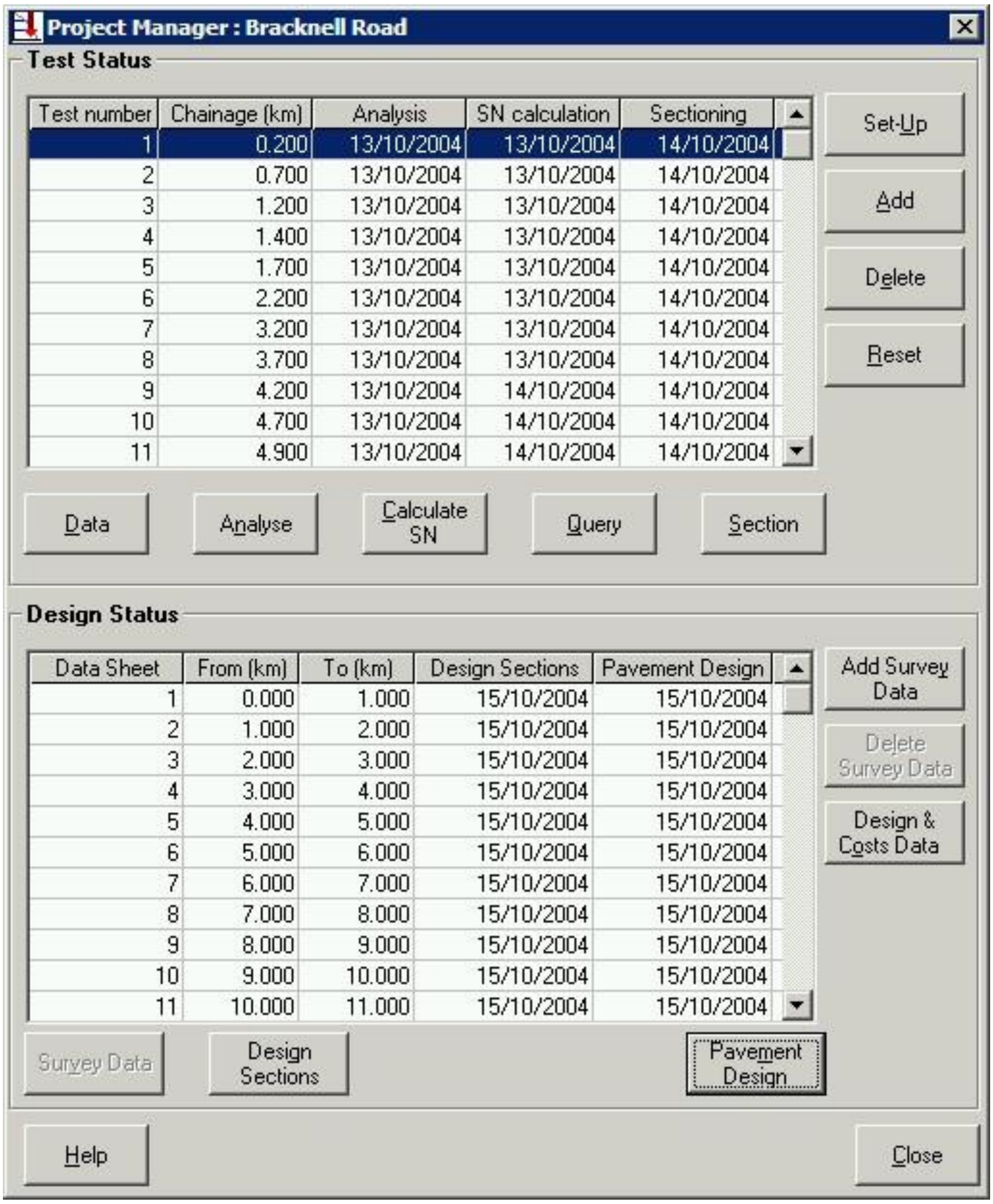

Figure 3.5 Project Manager (with test data and completed design)

The Design Status table has five columns.

Data Sheet	Data Sheets are automatically numbered in chainage order from 1 upwards. If a Data Sheet is added out of sequence or deleted, the numbering is automatically corrected.
From (km)	The start chainage of the Data Sheet in kilometres.
To (km)	The end chainage of the Data Sheet in kilometres.
Design Sections	The date when Design Sections were determined for the project. The cell is blank if these have not yet been determined.
Pavement Design	The date when the pavement design was produced. The cell is blank if this has not yet been done.

There are six buttons in the Design Status panel associated with pavement design.

Add Survey Data	Enter data from a new survey Data Sheet into the Design Status table.
Delete Survey Data	Delete a selected Survey Data Sheet from the Design Status table.
Design & Costs Data	Enter or edit Design Standards, Traffic and Costs data for the entire project.
Survey Data	Review or edit the details of a selected data sheet.
Design Sections	Divide the project into design sections. This button is inactive if DCP Sections have not yet been determined or if the entered survey data does not cover the entire project length.
Pavement Design	Produce a design. This button is inactive if Design Sections have not yet been identified.

4 Test data input

4.1 Introduction

This chapter describes how to input data for the penetration tests within a project.

For each penetration test, the following are required.

- Site details – information about the site where the test was carried out.
- Upper layers – information about the upper layers which cannot be analysed by a DCP.
- Penetration data – data which records the number of blows of the DCP and the depth of penetration
- Set-Up – information about how each test is carried out, analysed and displayed.

To input data from a new test, click *Add* in the Project Manager. To review or edit data from a test which has already been inputted, highlight the test in the Project Manager and click *Data*. Both actions will bring up the Test Details box (Figure 4.1) for that test. At any point during data input, *Cancel* can be clicked to cancel the entered information. This will generate a box asking if the changes that have been made should be saved. Clicking *No* will cancel any changes that were made.

Data may be input using alternative methods. These are described in **Error! Reference source not found.** below.

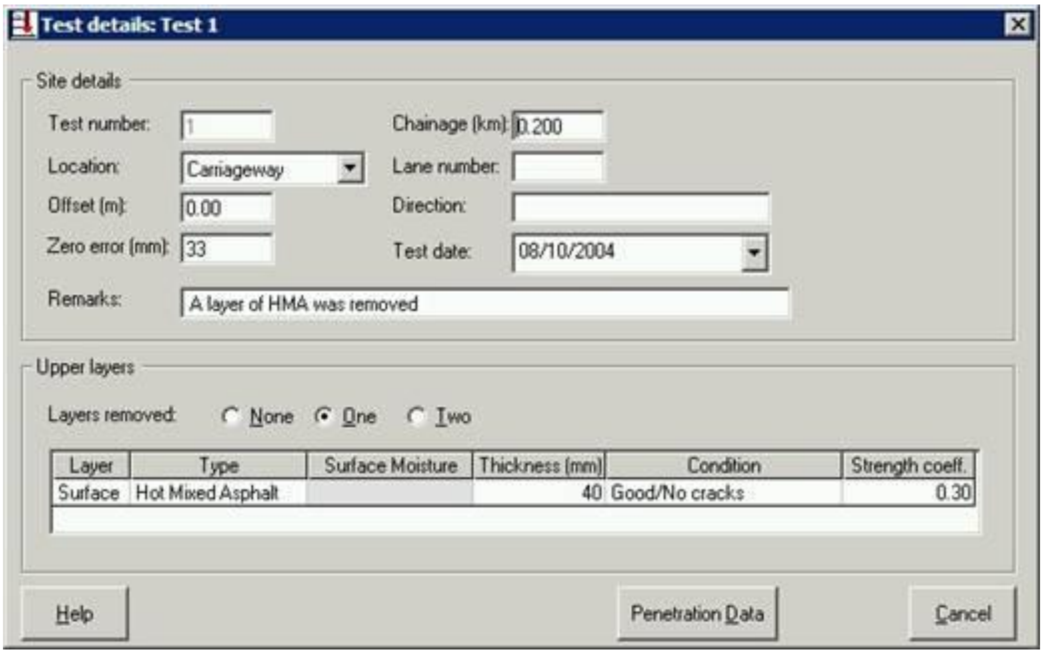

Figure 4.1 Test Details box

4.2 Site details

The top panel of the Test Details box is titled Site details and records information about the site where the test was carried out. The panel has a number of fields. These are mandatory (M), optional (O) or filled in automatically (A).

Test number	A	This field is filled in automatically according to the chainage and location of the test, as described in 3.2 above.
Chainage (km)	M	It is important that all tests within a project use the same chainage datum.
Location	M	Although penetration tests are normally carried out in the carriageway of a road, it may be necessary to measure the strength of the construction off the carriageway line. When results are analysed, it will be necessary to distinguish between these locations so that, for example, carriageway improvement works are not designed using layer strengths measured in a soft verge. Therefore, using the pull-down menu, select the location of the test from carriageway, shoulder, verge and lay-by / other. Carriageway is the default location.
Lane number	O	It may be necessary to record in which lane of a road a test was made. Thus this field may be required if tests are being carried out on a road with more than one lane in each direction. Any normal local convention can be used for numbering lanes.
Offset (m)	O	This refers to the offset from a datum line along the road. It is normal to use the carriageway edge as the datum, although the centre line of the road could be used instead.

Direction	O	This is the traffic direction of the lane where the tests are being carried out. Direction does not need to be recorded on a single lane road. The field is limited to 25 characters.
Zero error (mm)	M	The zero error is the reading on the vertical scale of the DCP when the cone is sitting on a flat surface and is a result of the way in which the instrument is manufactured and assembled. The zero error is measured by placing the DCP on a smooth, level, hard surface, lowering the cone to the surface and reading the scale. This should be done whenever the DCP is prepared for use and, ideally, before every new series of tests. The zero error should be entered for every test.
Test date	M	This defaults to today's date if this is the first test in a project. Otherwise the date entered for the previous test will appear. In both cases, the default date can be changed using the pull down calendar.
Remarks	O	These can be either typed or copied and pasted as required. The field is limited to 60 characters.

If the details of a test have already been entered, click *Edit* to be able to make changes, although if the data has already been analysed, a box will be generated warning that editing the data will delete this analysis.

4.3 Upper layers

UK DCP 3.1 uses penetration data to calculate the strength of most pavement layers. However, some layers are too thin, strong or impenetrable for relationships between penetration rate and strength to be derived. In this case, the strength of the layer is assessed from the type of the layer and its condition. This applies to layer types such as:

Surface

- Thin bituminous seal
- Hot mix asphalt
- Concrete
- Other surface

Base

- Cement treated base
- Bituminous base
- Coarse granular base (such as Water Bound Macadam)

Since these layers are always found at the top of a pavement, they are referred to as Upper Layers. Layers whose strength can be calculated from penetration data are referred to as Test Layers.

The calculation of layer and pavement strength for Upper layers and Test layers is explained in detail in 0 below.

The bottom panel of the Test Details box (Figure 4.1) is titled Upper layers. A selection must be made and a table must be

4.4 Penetration data

After completing the Test Details box with Site details and Upper layer information, click *Penetration Data* to open an empty Penetration Data box. This box has two panels.

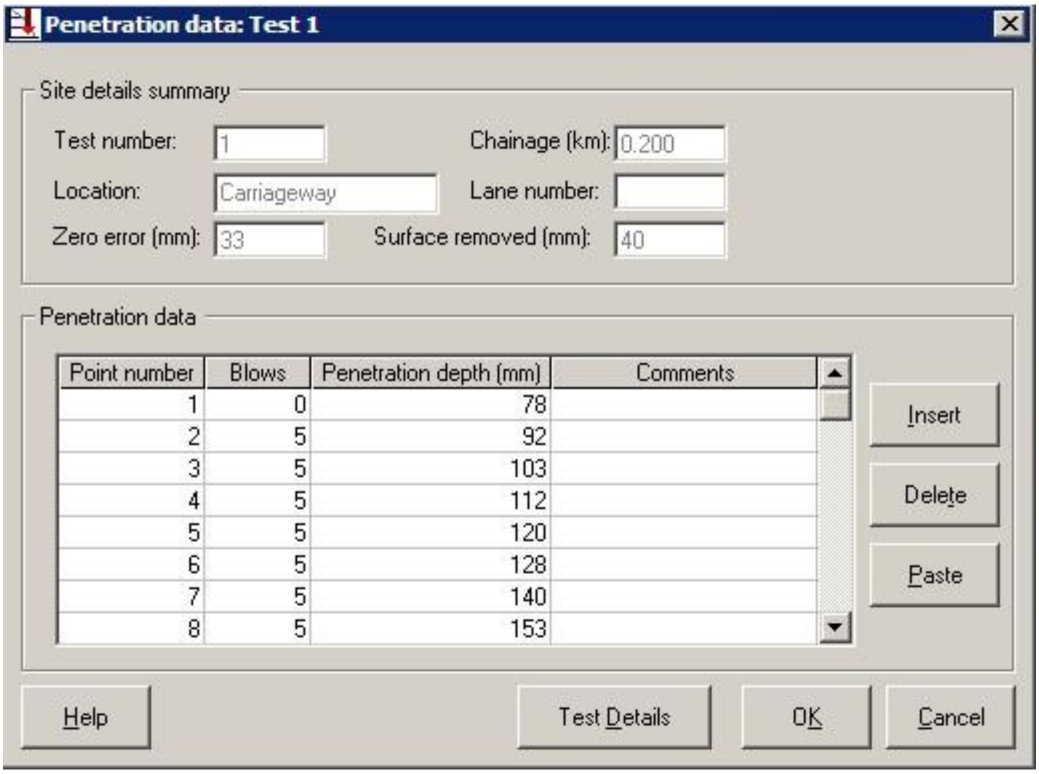

Figure 4.3 Penetration Data box (with test data)

4.4.1 Site details summary

This panel provides a summary of the site details which have already been entered. These details cannot be edited.

4.4.2 Penetration data

During a DCP test, the cone is driven into the pavement under repeated blows. The record from a test consists of a number of test points. At each test point the number of blows since the last test point is recorded and the total penetration of the cone is measured.

It is recommended that the penetration of the cone should be measured at increments of about 10 mm. However, it is usually easier to measure penetration after a set number of blows. It is therefore necessary to change the number of blows between measurements according to the strength of the layer being penetrated. For good quality granular bases, measurements every 5 or 10 blows are normally sufficient, but for weaker sub-bases and subgrades, measurements every 1 or 2 blows may be required. There is no disadvantage in taking too many readings but if too few are taken, there is a danger that weak spots will be missed and layer boundaries will be difficult to identify.

This data is entered into the table in this panel. Each row in the table represents one test point. The table has four columns.

Point number	The number of each test point. If a point is inserted or deleted, the numbering is automatically corrected. A maximum of 250 test points can be entered for each DCP test. If more than 250 have been recorded, it is likely that the cone hit an impenetrable object such as a stone, in which case the data is of no use.
Blows	The number of blows given to the cone to drive it from the previous point to the current point. The number of blows at the first test point is automatically set at zero. A maximum of 25 blows are permitted between each test point. If more blows are given, changes in depth are likely to be too high for useful results to be calculated.
Penetration depth (mm)	The depth at the current point, as read off the DCP scale. The depth of the first test point, the 'initial reading', is recorded before any blows have been given. Since the zero error (see above) is measured when the DCP is placed on a smooth and level surface, it is impossible for the initial reading to be less than the zero error. The initial reading also includes the thickness of all removed layers. It will not be accepted if it is less than the sum of the zero error and the thicknesses of the removed layers as if so, it is likely to be an error. Note that in Figure 4.3 the initial reading (78) is greater than the sum of the zero error (33) and the thickness of the removed layer (40). A maximum penetration depth of 1500 mm is allowed. If the cone has penetrated further than this, it is likely that friction along the rod is significantly reducing the penetration rate of the cone, in which case the data is unreliable and should not be used.
Comments	Comments are entered automatically if an impenetrable layer was drilled or if an extension rod was used (see **Error! Reference source not found.**).

4.5.1 CBR Calculation

The strengths of Test layers are calculated by converting the penetration rate (mm per blow) to a California Bearing Ratio (CBR) value and then from the CBR value to a strength coefficient and finally to a Structural Number. A number of relationships between penetration rate and CBR value have been derived and are given in Table 4.1. Some of these are used when the DCP cone has an angle of 60°, others when the cone has an angle of 30°. The relationship and the cone angle are selected on this panel. The user's organisation should provide guidance as to which relationship should be used or whether a new relationship for the local conditions should be developed. The default is the TRL relationship for a 60° cone.

The conversion of CBR value to strength coefficient and Structural Number is described in Chapter 6.

Table 4.1 Penetration rate-CBR relationships

Cone angle	Name of relationship	Relationship
60° cone	TRL[1]	$\text{Log}_{10}(\text{CBR}) = 2.48 – 1.057\ \text{Log}_{10}(\text{pen rate})$
	Kleyn[2] (pen rate > 2 mm/blow)	$\text{CBR} = 410\ (\text{pen rate})^{-1.27}$
	Kleyn[3] (pen rate ≤ 2 mm/blow)	$\text{CBR} = 66.66\ (\text{pen rate})^2 – 330\ (\text{pen rate}) + 563.33$
	Expansive Clay Method[4]	$\text{Log}_{10}(\text{CBR}) = 2.315 – 0.858\ \text{Log}_{10}(\text{pen rate})$
	100% Planings[5]	$\text{Log}_{10}(\text{CBR}) = 1.83 – 0.95\ \text{Log}_{10}(\text{pen rate})$
	50% Planings	$\text{Log}_{10}(\text{CBR}) = 2.51 – 1.38\ \text{Log}_{10}(\text{pen rate})$
	User-Defined	$\text{Log}_{10}(\text{CBR}) = [\text{constant}] – [\text{coefficient}]\ \text{Log}_{10}(\text{pen rate})$ Constant and Coefficient can be defined by the user
30° cone	Smith and Pratt[6]	$\text{Log}_{10}(\text{CBR}) = 2.555 – 1.145\ \text{Log}_{10}(\text{pen rate})$
	User-Defined	$\text{Log}_{10}(\text{CBR}) = [\text{constant}] – [\text{coefficient}]\ \text{Log}_{10}(\text{pen rate})$ Constant and Coefficient can be defined by the user

(pen rate is the penetration rate measured in millimetres per blow)

Layers can be identified either automatically by UK DCP 3.1 or manually by the user. This panel allows the method of identification to be selected. The default is automatic analysis.

4.5.3 Analysis

Layers can be identified either automatically by UK DCP 3.1 or manually by the user. This panel allows the method of identification to be selected. The default is automatic analysis.

4.5.4 Display Options

When penetration data is being analysed, a graph of penetration depth against the number of blows given to the DCP is used to identify layers of different materials and the boundaries between them. The remaining two panels allow changes to be made to this graph which may help in identifying layers.

Design Thickness

It is sometimes difficult to identify layers from a penetration graph and, even if layers can be seen, it can be difficult to be sure whether the layer is part of the base, sub-base or subgrade. If actual information on materials and layer thicknesses is available, layer identification from penetration data can be much easier. This information can come from records made when the pavement was being constructed or from test pits dug alongside and within the project. Neither source of information will accurately predict the layers at each test site, but they can provide useful guidance. If as-built or test pit information is available, click in the *As-Built Thickness Known?*box and enter the recorded thicknesses for the Surface, Base and Sub-base. These will be displayed on the penetration graphs, as shown in, for example, Figure 5.2 and **Error! Reference source not found.**. The default is to not display as-built thicknesses.

Display

Different colours are used to indicate different elements of the penetration graph. They can be changed if required, for example if a printer does not print a particular colour well. The defaults are Data Point – dark green; Test Layers – dark blue; underside of Upper Layers – bright blue; Drilled Layer – red.

After data from penetration tests has been input, the Project Manager is as shown in Figure 4.6.

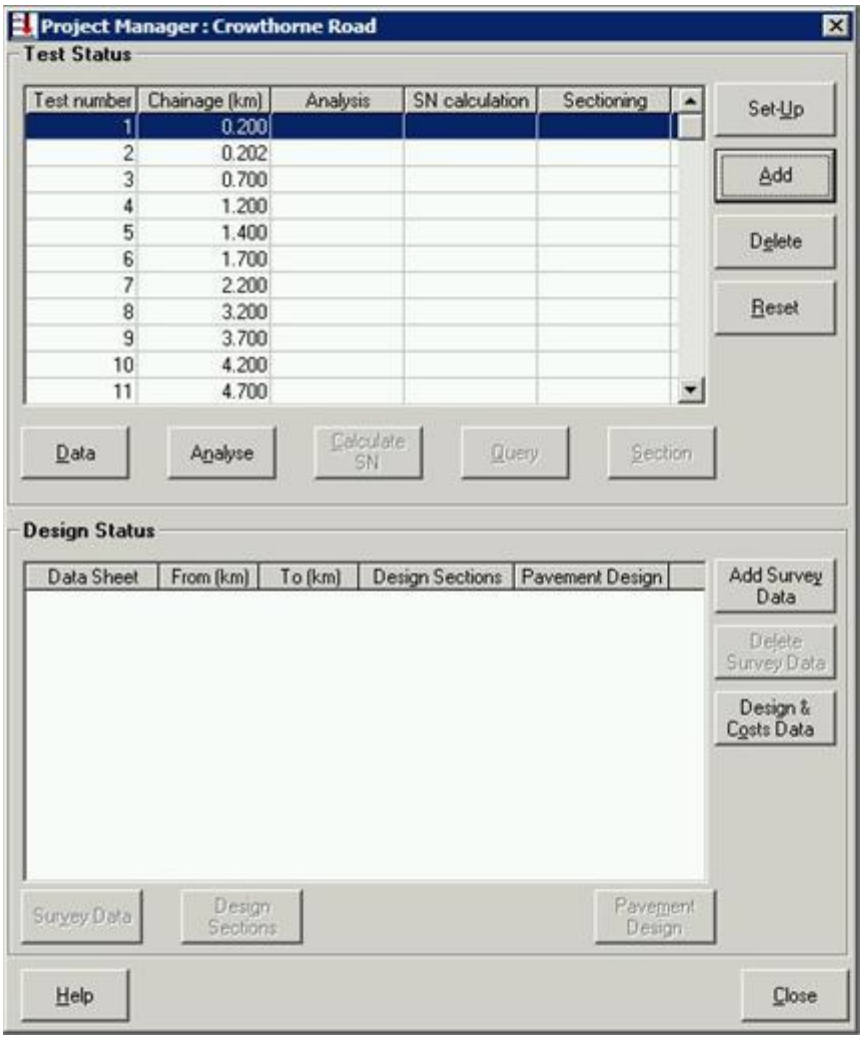

Figure 4.6 Project Manager (showing that test data has been input)

Layer analysis

5.1 Introduction

A typical graph of penetration depth against the cumulative number of blows given to the DCP shows a line of varying gradient. The gradient is equal to the penetration rate of the cone as it is driven into the pavement.

For Test layers, it is possible to derive relationships (0) between the penetration rate and the strength of the material through which the cone is passing. The gradient of the line can therefore be used to calculate the material strength. Changes in the gradient of the line indicate boundaries between materials of different strengths and hence the thicknesses of layers of different strengths.

Upper layers are often too thin, strong or impenetrable for their strength to be determined from the penetration rate. Instead, the strength of an Upper layer is estimated from the type of the layer and its condition, and its thickness is taken from as-built records, test pit data or by measuring the thickness of a layer removed during the DCP test.

This chapter describes how the thicknesses of Test layers are determined from penetration graphs; Chapter 6 then describes how the strengths of Upper layers and Test layers are calculated.

The penetration graph can be analysed automatically or manually according to the selection made when defining Set-Up information (0).

5.2 Analysing Test layers

Begin layer analysis from the Project Manager. Highlight a test which has not yet been analysed and click *Analyse* in the Project Manager or in the Modules menu at the top of the main window.

This will open a Layer Boundaries box. It contains a graph of adjusted penetration depth (data adjustment is explained in Box 4.2 Calculating adjusted penetration data

against the cumulative number of blows given to the DCP. All test points are plotted onto the graph. The gradient of the line of test points is the penetration rate of the cone and hence the strength of the material at that depth. A shallow gradient indicates strong material, a steep gradient indicates weak material and changes in gradient indicate a layer boundary between Test layers of different strengths.

The other information displayed on the graph depends upon whether layer analysis will be carried out automatically or manually. These two alternatives are compared in Box 5.1 and described in detail below.

Box 5.1Should penetration data be analysed automatically or manually?

UK DCP 3.1 allows penetration plots to be analysed automatically or manually. Each method has advantages and disadvantages.

Automatic analysis

Advantages

Quicker than manual analysis.

Disadvantages

The user has no control over where layer boundaries are located.

Assigns CBR to a drilled layer.

Summary

Automatically identified layer boundaries of a complex plot may be located inappropriately. Automatic analysis is therefore recommended when the penetration plot has a simple shape.

Manual analysis

Advantages

User has more control over where layer boundaries are located.

The use of gaps can improve the analysis of drilled and strong layers.

Disadvantages

Slower than automatic analysis.

Summary

Manual analysis is recommended when the penetration plot has a complex shape, the analysis of which the user would like to have some control over. It is also recommended if an atypical item such as a large stone slowed down the penetration or had to be drilled.

5.3 Automatic layer analysis

The automatic layer analysis procedure first calculates the penetration rate at each test point and the average penetration rate for the entire test. For each test point it then calculates the value of the average rate minus the rate at that point. These values are then summed in turn starting at the first test to find the cumulative difference sum at each point. By the nature of the calculation, this sum will be zero at the final test point. At one point this sum will reach a maximum absolute value. The depth of the point at which the sum reaches this maximum value is defined as the first Test layer boundary. This procedure has a similar effect to drawing a straight line from the first point to the last point and finding the depth of the intermediate point which is furthest from this straight line (as shown in Figure 5.1).

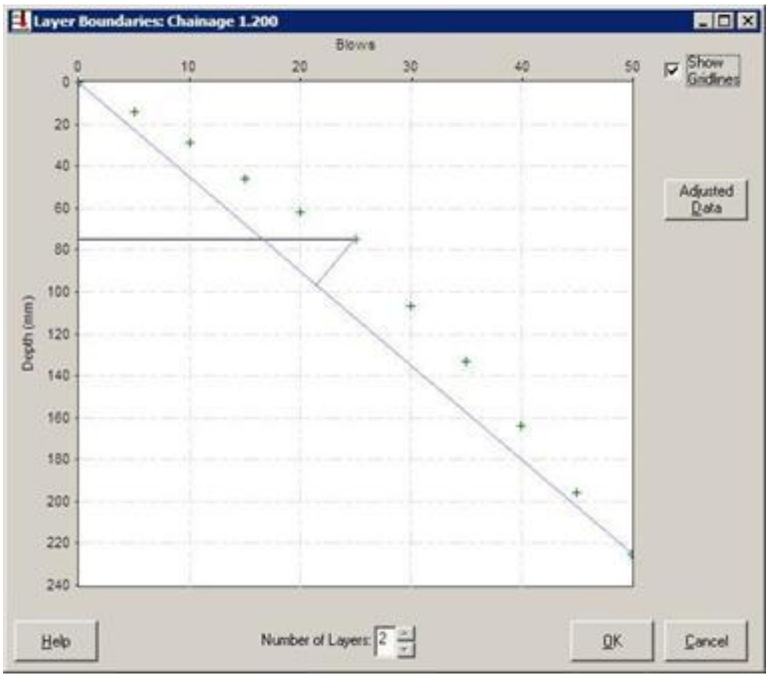

Figure 5.1 How Automatic analysis works

The procedure is then repeated for the test points above this first boundary and for the points below it. In this way the second and third boundaries can be identified. The procedure is repeated until the points between any two boundaries do not exhibit sufficient fluctuation from a straight line to allow a further boundary to be identified with any degree of confidence. An automatically analysed penetration plot is shown in Figure 5.2.

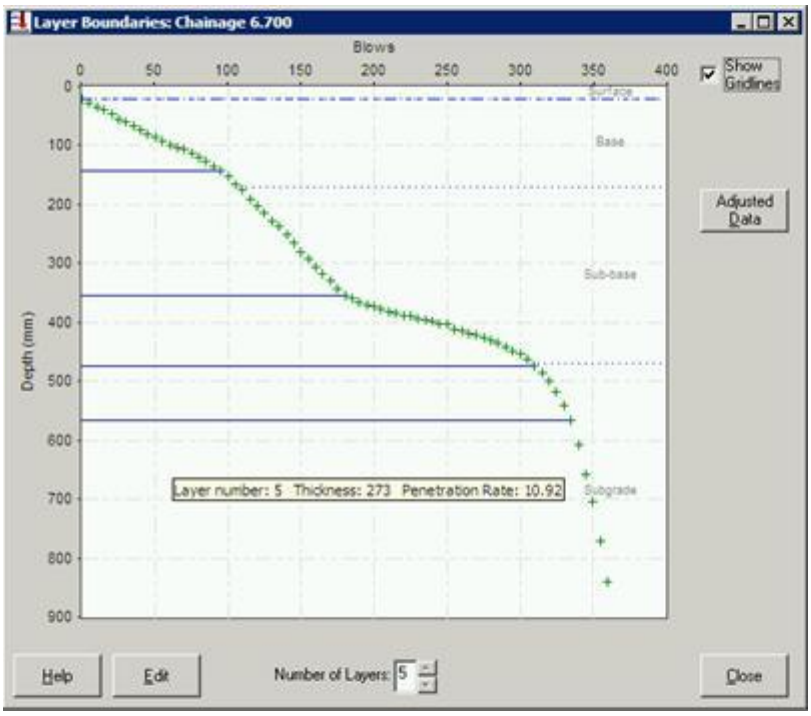

Figure 5.2 Layer boundaries box using Automatic analysis

To illustrate automatic layer analysis, Table 5.1 contains penetration data to a depth of 225 mm. The data is analysed in the table to show how a change from strong to weaker material can be identified at a depth of 75 mm. Figure 5.1 contains a graph of the data in this table. It shows how the point with the greatest cumulative difference sum is also the point which lies furthest from a straight line from the first point to the last point. The first Test layer boundary has been automatically generated and is shown on the graph.

Table 5.1 Example of penetration data and cumulative sum analysis

Point	Blows	Adjusted pen depth	Pen rate (mm/blow)	Av. Pen rate	Av. Pen rate – pen rate	Cumulative difference sum
1	0	0				
2	5	14	2.8	4.5	1.7	1.7
3	5	29	3.0	4.5	1.5	3.2
4	5	46	3.4	4.5	1.1	4.3
5	5	62	3.2	4.5	1.3	5.6
6	5	75	2.6	4.5	1.9	7.5 ← maximum value
7	5	107	6.4	4.5	-1.9	5.6
8	5	133	5.2	4.5	-0.7	4.9
9	5	164	6.2	4.5	-1.7	3.2
10	5	196	6.4	4.5	-1.9	1.3
11	5	225	5.8	4.5	-1.3	0

Five points should be noted when using automatic layer analysis.

- Boundaries can be identified only at depths corresponding to actual test points.
- The strength of a layer is calculated by the gradient of a straight line from the intersection of its upper boundary with the line of test points to the intersection of its lower boundary with the line of test points.
- There are three situations where minor corrections are made to the analysis in order to prevent inaccurate calculation of the thickness of the first Test layer. These are described in **Error! Reference source not found.**.
- **Error! Reference source not found.** below recommends when automatic layer analysis should be used for penetration data containing drilled layers.
- **Error! Reference source not found.** below recommends when automatic layer analysis should be used for penetration data containing strong but penetrable layers.

The following items are displayed in the Layer Boundaries box if automatic layer analysis has been selected. The colours of some of the items depend upon selection made when defining Set-Up information.

Maximum layers message	When the box is opened, a message will be generated giving the maximum number of Test layers which can be identified from the data using the above procedure. Click *OK* to delete this message. If 10 Test layers can be identified (the limit set by UK DCP 3.1), a message is not generated.
First layer boundary	The first layer boundary identified using the above procedure is shown with a horizontal line.
Number of Layers field	The number in this box is the number of Test layers currently being shown. Clicking the Up and Down arrows increases and decreases this number and adds or removes layer boundaries from the graph. The number can be increased up to the number which was shown in the Maximum layers message. Unless a drilled layer is present, this number is initially 2.
Upper layer line	A dashed line indicates the underside of the Upper Layers.
Drilled layers	If a layer has been drilled, it will be marked on the graph with two horizontal dotted lines, but the first automatic layer will not be shown. The Number of Layers field will therefore initially show 3, the portion above the drilled layer, the drilled layer itself and the portion below. An automatically analysed drilled layer is shown in **Error! Reference source not found.** below.
As-built layers	If as-built or test pit information was entered into the Set-Up of the test (0), these layers are shown, separated by dotted lines.
Show Gridlines	A check box is provided to allow gridlines to be displayed or removed.
Adjusted Data button	Click this button to generate a box showing the penetration data (**Error! Reference source not found.**). This data has been adjusted as described in Box 4.2Calculating adjusted penetration data

	. The box also includes the average penetration rate between successive points. This box is generated to guide the identification of Test layers and cannot be edited.
Help button	This button opens this manual on the screen at the appropriate section.
OK button	This is used to accept and save the layer boundaries and return to the Project Manager.
Cancel button	This is used to cancel the analysis. If changes have been made to the analysis, a box is generated which offers an opportunity to save the changes.
Layer descriptions	When the cursor is placed over the graph, a small box is generated. This box gives the number of the Test layer, its thickness (mm) and the average penetration rate for the layer.
Point descriptions	When the cursor is placed over a test point, a small box is generated. This box gives the cumulative blows and the adjusted depth of the point.

Add or remove layer boundaries from the graph until satisfied that the data has been adequately analysed. In Figure 5.2 five Test layers appear sufficient. Adding further layers does not increase the precision of the analysis. Note that identified Test layers matching previously defined as-built layers is a useful check on the analysis.

Click *OK* to save the analysis and return to the Project Manager. It will be seen (Figure 5.3) that today's date will be in the Analysis column for that test.

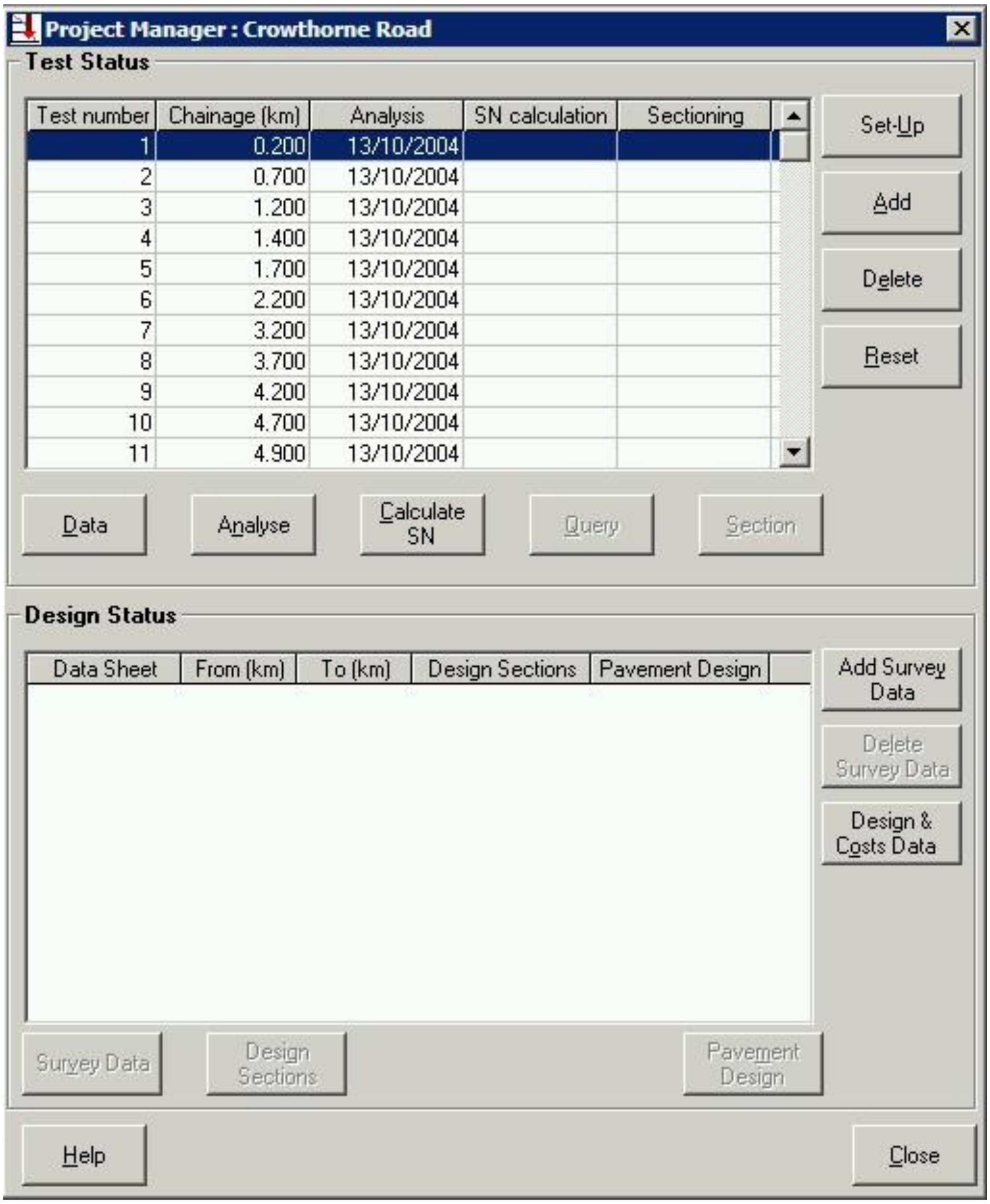

Figure 5.3 Project Manager (showing that test data has been analysed)

It is possible to examine the graph and possibly edit the analysis of a test for which layers have already been identified. Highlight the test in the Project Manager and click *Analyse*. The Layer Boundaries box will be opened and the penetration graph will be shown, but *Edit* must be clicked before changes can be made to the number of Test layers. When *Edit* is clicked, if SN Calculations have already been carried out, a warning appears that SN Calculation data, and possibly Sectioning data will be deleted. If it is not necessary to edit the analysis, click *Close* to return to the Project Manager.

Structural Number calculation

6.1 Introduction

Assessing the strength of a pavement is difficult. Most pavements have several layers and for each one many different characteristics can be measured: thickness, modulus, CBR and so on. These values can be combined in many different ways. The concept of a Structural Number [(8)] (SN) was developed during the AASHO Road Test research as a single number which would indicate the strength and durability of an entire pavement and which would be internationally recognised. The concept was developed for the analysis of flexible pavements; rigid pavements are not analysed using Structural Numbers.

Over time, the concept has expanded. The original term, SN, was calculated from the imported surface, base and sub-base layers. The modified Structural Number [(9)] (SNC) was then introduced to include the effect of the subgrade. However, it was realised that because the subgrade contribution to SNC is independent of its depth, redefining subgrade material as sub-base gives a higher SNC. Tests were carried out and the adjusted Structural Number [(10)] (SNP) was developed. This adjusts the contribution of the sub-base and subgrade according to their depth and eliminates this potential source of error.

This chapter describes how to calculate the Structural Number of each pavement layer. It provides the equations used to calculate SN and SNC, although those used to calculate SNP are too extensive to be included here.

6.1.1 Upper layers

Upper layers are layers at the top of the pavement which are too thin, strong or impenetrable for relationships between penetration rate and strength to be derived. The contribution of an Upper layer to the Structural Number of a pavement is its strength coefficient multiplied by its thickness. The strength coefficient is assessed from the type of the layer and its condition, as described in **Error! Reference source not found.** above.

6.1.2 Base and Sub-base Test layers

The contribution of a Base and Sub-base layer to the Structural Number of a pavement is its strength coefficient multiplied by its thickness.

$$SN = \Sigma a_i d_i$$

where:	i	is a summation over layers
	a_i	is a strength coefficient for each layer
	d_i	is the thickness of each layer measured in inches

The strength coefficient of a layer can be calculated from its CBR value, which is calculated from the penetration rate as described in 0 above.

The relationship between CBR and strength coefficient depends upon the layer and the material. These relationships are given in Table 6.1.

Table 6.1 CBR-Strength Coefficient (a) relationships

Pavement Layer		Relationship
Base		$a = 0.0001\ [29.14\ (CBR) – 0.1977\ (CBR)^2 + 0.00045\ (CBR)^3]$ This relationship is also used for a gravel or earth surface layer (11).
Cement treated base	CBR > 70%	$a = 0.00016\ [29.14\ (CBR) – 0.1977\ (CBR)^2 + 0.00045\ (CBR)^3]$
	CBR < 70%	a = 0. Tests have shown that a cement treated base with a CBR less than 70 has minimal effective strength.
Sub-base		$a = 0.184\ Log_{10}(CBR) – 0.0444\ (Log_{10}(CBR))^2 – 0.075$

6.1.3 Subgrade Test layers

The contribution of the Subgrade to the Structural Number of a pavement is referred to as SNG and is calculated directly from CBR without the need for an intermediate strength coefficient. SNG is a function of the CBR of the entire subgrade, rather than any layers into which the subgrade can be divided. A procedure to identify the layers which have the greatest influence within the subgrade and derive the aggregate subgrade CBR in a manner which reflects engineering judgement has therefore been devised and is included in UK DCP 3.1.

The relationship between subgrade CBR and SNG is as follows.

$SNG = 3.51\ Log_{10}(CBR) – 0.85\ Log_{10}(CBR)^2 – 1.43$

6.2 Calculating the Structural Number

Begin the Structural Number calculation from the Project Manager. Highlight a test for which Structural Numbers have not yet been calculated and click *Calculate SN* in the Project Manager or in the Modules menu at the top of the main window. This button is inactive if the selected test has not yet been analysed.

This will generate an SN Calculation box (Figure 6.1). This box has three panels and five buttons, although the third panel is not visible until the second panel has been completed.

It is possible to view the results and possibly edit the analysis of a test for which Structural Numbers have already been calculated. Highlight the test in the Project Manager and click *Calculate SN*. The results will be shown, but *Edit* must be clicked before changes can be made. When *Edit* is clicked, if the project has already been sectioned, a warning appears that sectioning results will be deleted if editing continues.

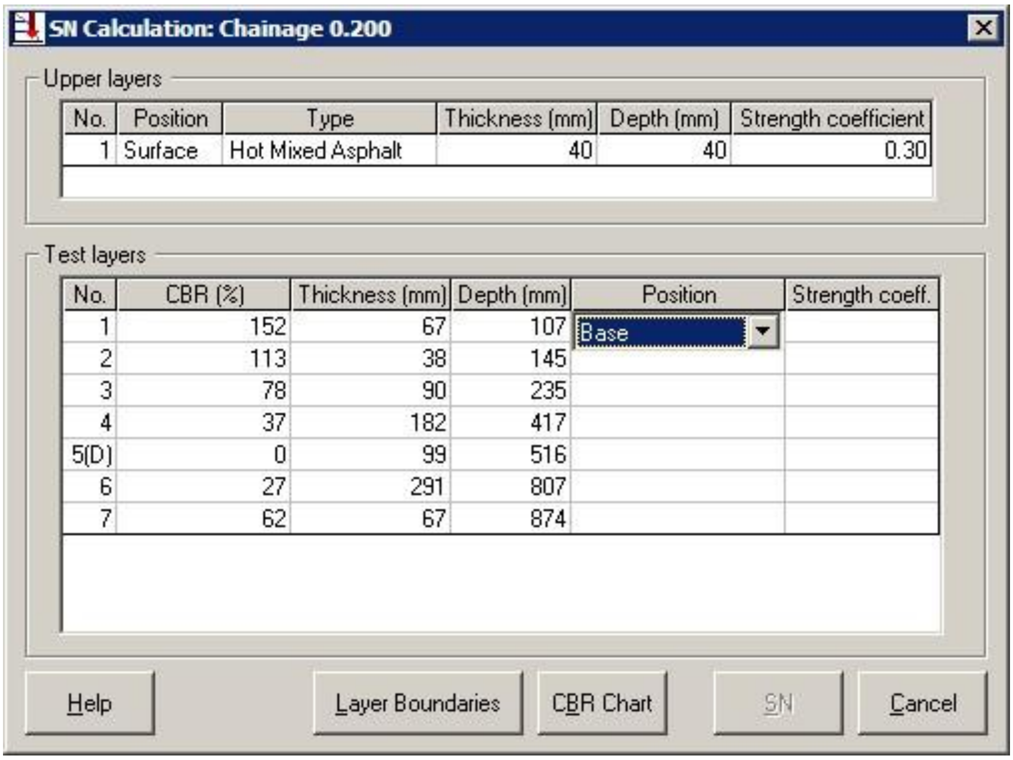

Figure 6.1 SN Calculation box (before calculating SNs)