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Guidelines for the Use of the Falling Weight Deflectometer in Ireland

CC-GSW-04008

July 2000

CC Construction & Commissioning

Technical

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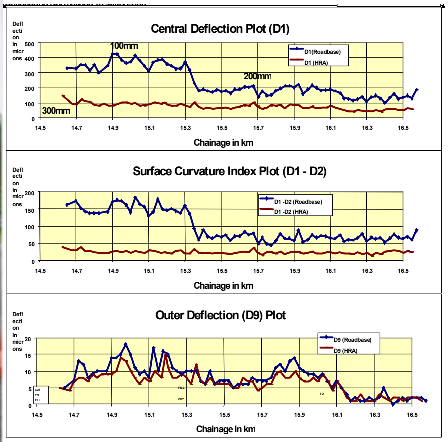
NRA DMRB and MCDRW References

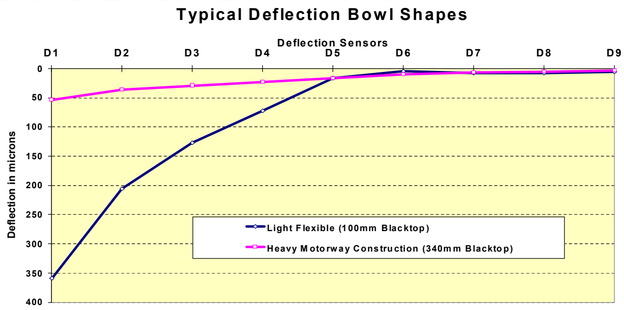
For all documents that existed within the NRA DMRB or the NRA MCDRW prior to the launch of TII Publications, the NRA document reference used previously is listed above under 'historical reference'. The TII Publication Number also shown above now supersedes this historical reference. All historical references within this document are deemed to be replaced by the TII Publication Number. For the equivalent TII Publication Number for all other historical references contained within this document, please refer to the TII Publications website.

National Roads Authority

Pavement and Materials Research Division

Guidelines for the use of the Falling Weight Deflectometer in Ireland





NATIONAL ROADS AUTHORITY

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Index for FWD Report

1. Introduction

Non destructive deflection testing of road and airfield pavements are carried out using a variety of methods including Benklman Beam, Deflectograph, Dynaflect and Falling Weight Deflectometer (FWD). The FWD is widely used throughout Europe for evaluating the bearing capacity of pavements. There are in excess of 100 machines in use in Europe and in excess of 300 worldwide. A review of the use of FWD's throughout Europe (COST 336) has recently been completed and the document is due to be published in late 2000. The publication will form a guidelines document for the use of the FWD under the three main headings, Use at Project level, Use at Network level and Calibration protocols for FWD.

The type of materials which will be referred to in this document are those which are used in flexible and semi-flexible pavements. Rigid pavements are not dealt with in this document.

The aim of any non-destructive test device is to provide information on the bearing capacity of a pavement due to the action of wheel loads. Studies(1) have shown that the load pulse generated by a FWD is similar to that produced by a wheel travelling at a speed of 60 to 80 km/h.

An advantage of the FWD system over some other deflection devices is that deflections are measured at a number of locations remote from the load application. This provides useful information on the overall bearing capacity of the pavement being tested.

The FWD machine is static during the testing sequence and so requires safe traffic management during survey. For this reason, the use of FWD is usually restricted to project level analysis. A number of prototype devices are currently being manufactured that are designed to measure deflections at traffic speeds thus removing the need for traffic management. The advent of such devices would allow more scope for routine deflection testing on a network level basis.

2. Description of FWD

2.1 General Description of FWD

During FWD testing, a load pulse is achieved by dropping a constant mass with rubber buffers through a particular height onto a loading platen. The load is usually transmitted to the pavement via a 300mm diameter loading plate. The loading plate has a rubber mat attached to the contact face and should preferably be segmented to ensure good contact with the road surface. An example of a segmented loading plate is shown in Figure 1. A load cell placed between the platen and the loading plate measures the peak load. The resulting vertical deflection of the pavement is recorded by a number of geophones, which are located on a radial axis from the loading plate. One of the deflection sensors is located directly under the load as shown in Figure 1. A typical FWD test set-up is shown diagrammatically in Figure 2.

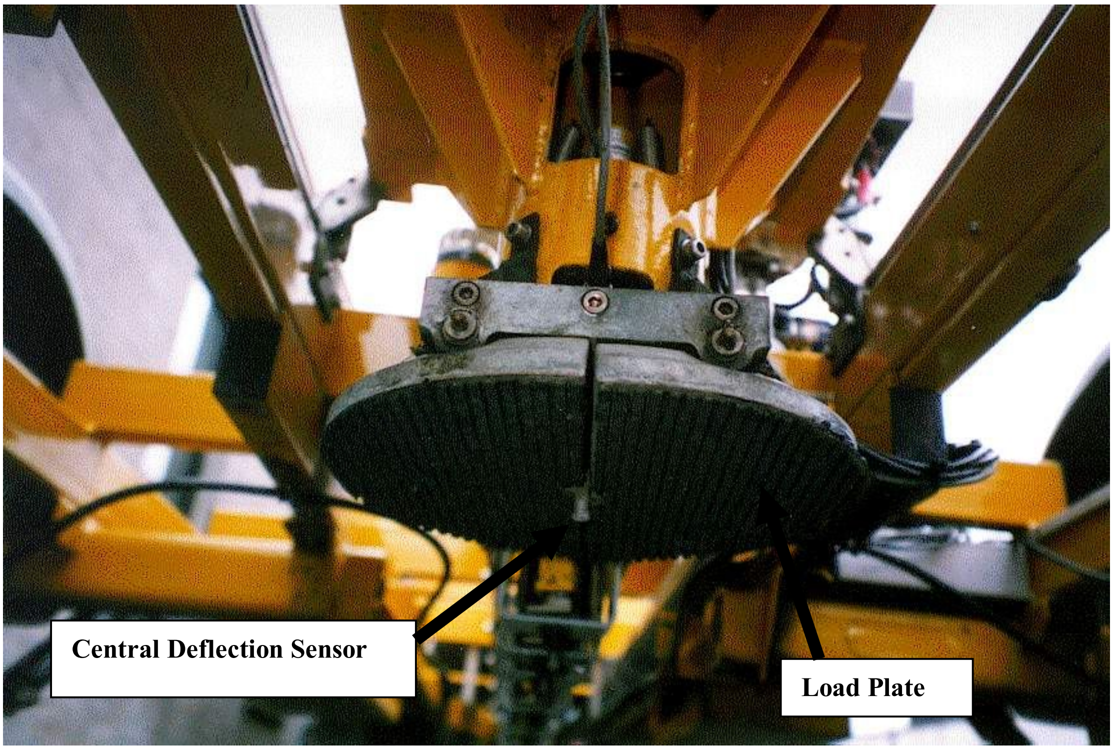

Figure 1: Segmented FWD Load Plate

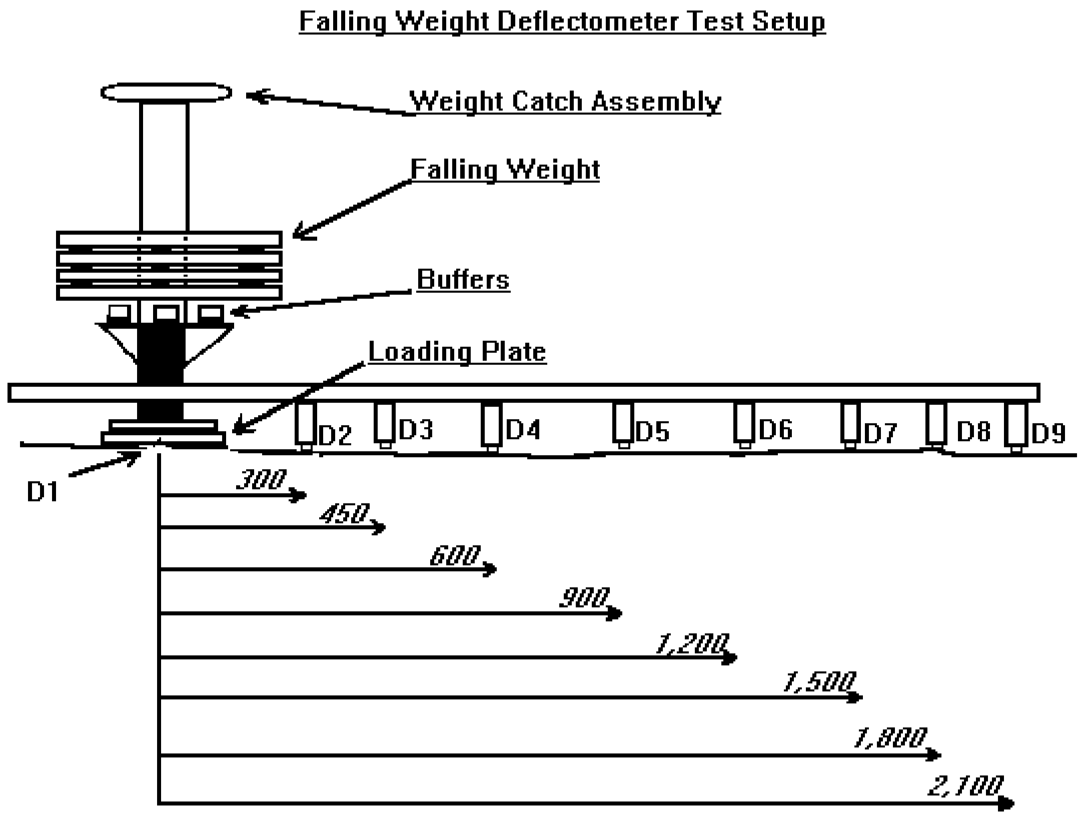

Figure 2: Diagramatic Representation of FWD

2.2 Load Pulse

As stated earlier the load pulse is achieved by dropping a constant mass onto a loading platen via rubber buffers. Differences in manufacturers design have resulted in varying pulse shapes for the same peak load. However, most FWD's have a load rise time from start of pulse to peak of between 5 and 30 milliseconds and have a load pulse width of between 20 and 60 milliseconds[1]. The shape of the load pulse is intended to be similar to that produced by a moving wheel load. Figure 3 shows a typical longitudinal strain profile for a wheel moving at 100 km/h on a rolled asphalt roadbase[2]. Figure 4 shows a typical deflection profile for a FWD load pulse.

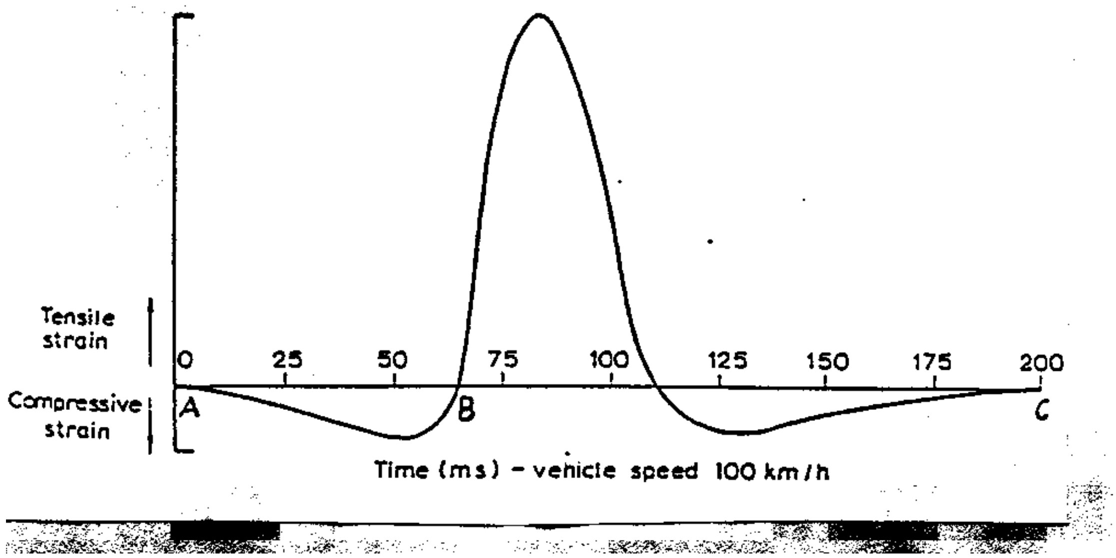

Figure 3: Typical Longitidunal Strain Profile for Moving Wheel (100 km/h)

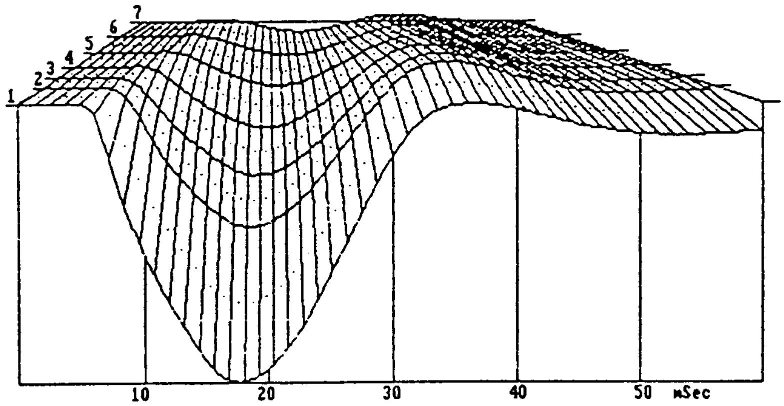

Figure 4: Deflection Response of FWD Load Pulse

Most FWD's have a load pulse range of between 25 and 120kN approximately. Some machines are capable of achieving larger loads, which may be required for airfield work. The target load pulse used for analysis is usually either 40 or 50kN (Standard Wheel Load). The range of design axle loads (wheel load x2) currently used in Europe is shown in Figure 5[(3)].

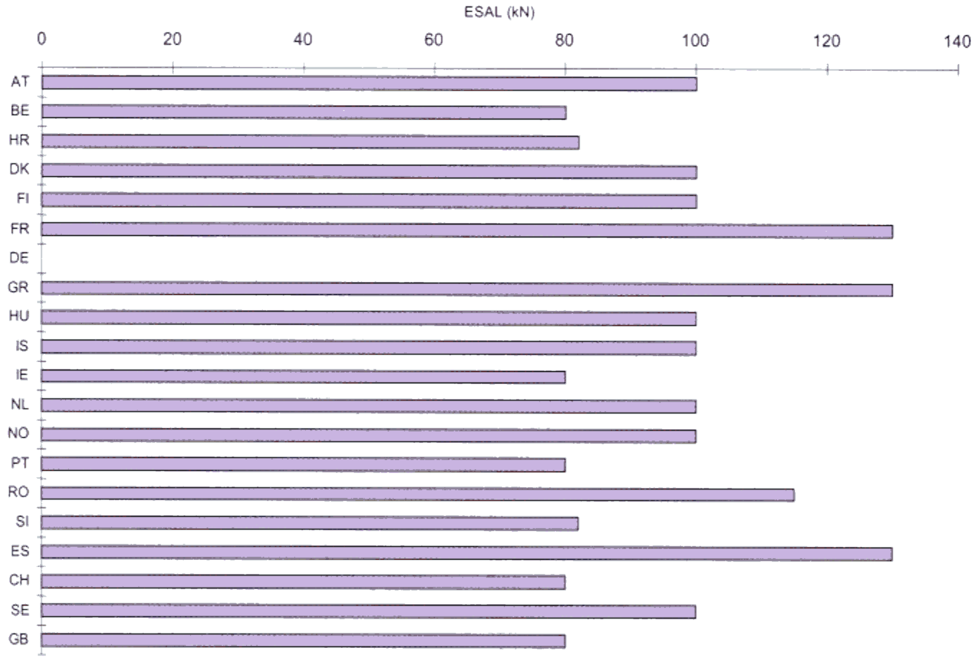

Figure 5: Design Axle Loads Used in Europe[3]

2.3 Deflection Sensors

The deflection sensors must be capable of reading deflections to resolutions of 1um (0.001 mm). At the same time they must be sufficiently robust to withstand site conditions. There must also be sufficient number of sensors to ensure that the full influence of the load pulse on the pavement is recorded.

The position of the sensors is usually chosen from the following list[1];

0, 200, 300, 450, 600, 900, 1200, 1500, 1800, 2100, 2400mm

2.4 Calibration Procedures

2.4.1 Relative Control

Calibration of FWD devices is extremely important and is described in FEHERL[(1)] document. A substantial section of the COST 336 document is also given over to calibration protocols. Relative calibration of the machine should be carried out approximately every month depending on usage. This can be done by testing in a location where deflections under the load plate of the order of 300 to 600um can be obtained for a load of 50kN. Both the load and sensor repeatability checks can be carried out at the same time.

a) A series of 12 drops at 50kN should be carried out. The first two drops are then discarded. In the case of each deflection sensor the standard deviation of the remaining ten drops, normalised to 50kN is then calculated. The standard deviation for each sensor must be less than or equal to 2um or 1.25% of the mean value of the reading + 1.5um (whichever is greater).

b) The first two drops are also discarded in the case of the load calibration. The standard deviation of the load should be less than 2% of the mean of the remaining ten readings.

An example of a series of relative calibration tests is shown in Figure 6 for a period of four years and a temperature range of approximately $5^{o}C$ to $25^{o}C$.

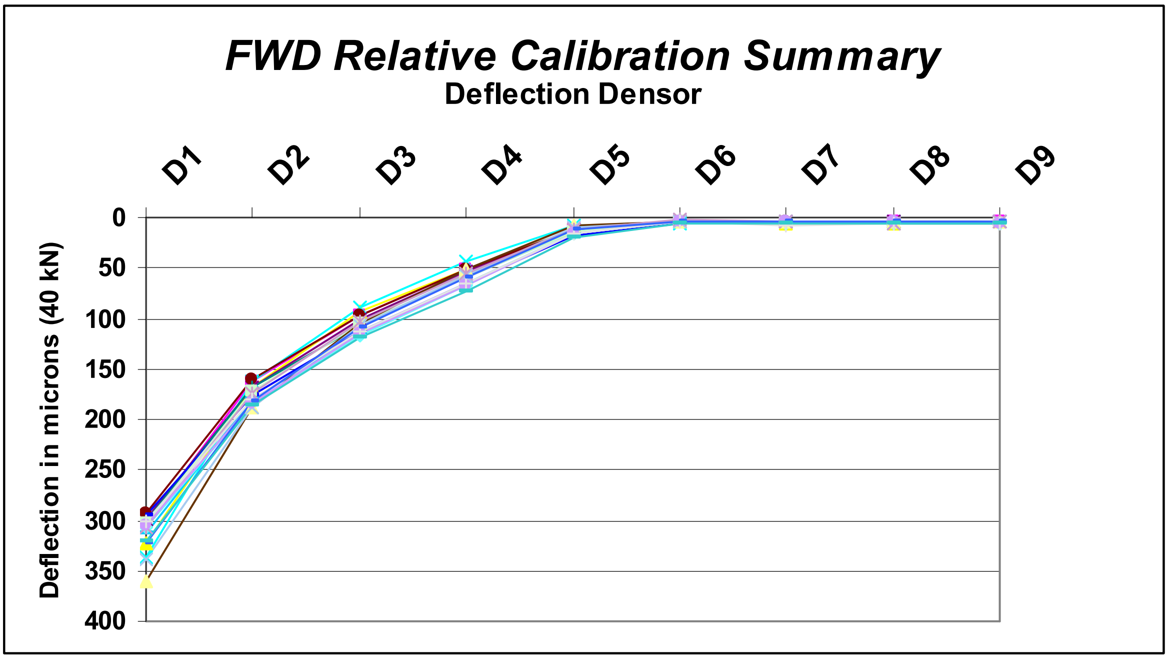

Figure 6: Relative Calibration Deflection Bowls

2.4.2 Calibration of Load Cell and Deflection Sensors

The load cell and deflection sensors should be calibrated every year. This can be done by removing the load cell and deflection sensors from the machine and having them calibrated. There is also the possibility of calibration of the load cell and deflection sensors while still mounted on the FWD machine. An example of a calibration certificate is shown in Appendix A.

2.4.3 Correllation Trials for FWD's

Correlation trials have been set-up in Europe and more recently in the UK as a quality control process for FWD machines. It is now mandatory in Ireland that any FWD to be used on the national road network must have a current certificate of acceptance from a correlation trial. The first full correlation trial took place on the small roads system in the TRL on 7 March 2000.
The trial consisted of a series of twelve test points of varying bearing capacity. Each FWD carried out a series of tests on each test point. The FWD operators travelled in convoy as shown in Figure 7. The results were then checked for consistency using predefined statistical limits. Certificates were issued by the

Highways Agency following the trials. An example of such a certificate is shown in Appendix B.

Figure 7: FWD Correllation Trial in TRL

3. Measurement Procedures

3.1 Preparation for Measurements

The appropriate traffic management must be arranged well in advance of the FWD survey being carried out. This is usually done in consultation with the relevant local Authority Engineers. The type of management required will depend on the particular site.
The FWD survey can commence as soon as the traffic management has been set up. FWD tests are generally carried out at 25 or 50m intervals on flexible roads. The load and deflection data is recorded using a laptop computer inside the towing vehicle. The testing sequence including number of drops and drop heights is set-up using software supplied with the FWD device.

3.2 Choice of Test Lane, Test Load

The location of the FWD tests will usually be governed by the information, which is required from the FWD survey. In many cases the tests will be carried out in the inner wheel track of the slow lane (if applicable). The reason for this choice is that this is often the first location to show distress signs on a road pavement. Tests can also be carried out between the wheel tracks for comparison purposes and to ascertain the residual life of the relatively untracked pavement.

FWD surveys on two way single carriageway roads can be carried out in one direction or alternatively in both directions using "staggered" locations as shown in Figure 8.

It is generally recommended(1) that at least three loading cycles, excluding a small drop for settling the load plate should be made at each location. The first drop is usually omitted from calculations. A drop sequence of four drops ranging from 27kN to 50kN approximately allows data analysis to be carried out at either the 40 or 50kN load level as required. Each drop sequence takes approximately one minute or less.

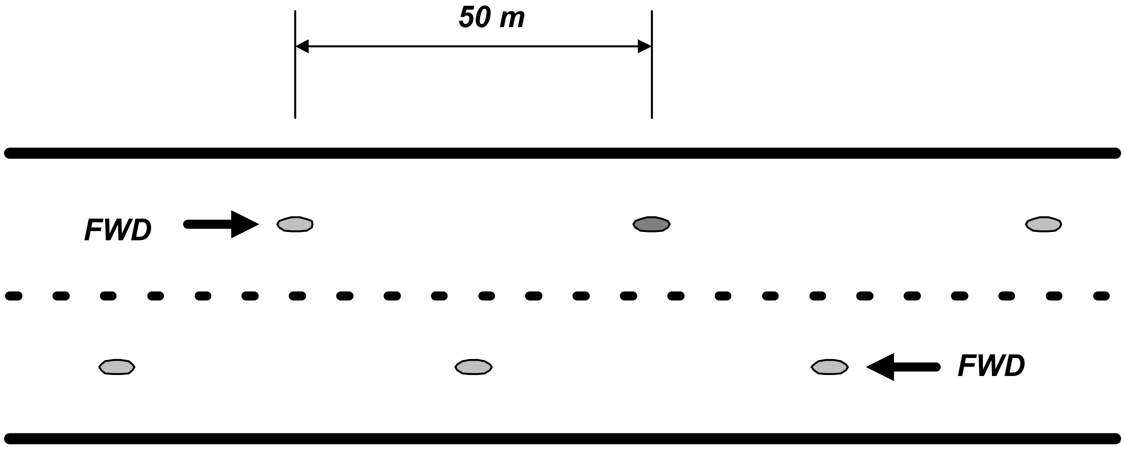

Figure 8: Staggered FWD test points on two lane road

3.3 Data Required per Test Length

The following data should be recorded for each test length: This data should be recorded and saved in a file format similar to the example shown in Appendix C (.F20).

- Deflection sensor offsets
- Base plate diameter
- Deflection sensor numbers and gain factors
- Test program filename and drops stored on file
- Name and number of test length, carriageway
- Name of operator
- Date of survey
- State of filtering/ smoothing option and cut off frequency

The following data should be recorded for each test point:

- Location (chainage, lane, transverse position in the lane)
- Time and date

- Air temperature
- Pavement temperature (if measured)
- Peak Load and Peak Deflections for each drop recorded
- Drop number
- Relevant comment e.g. Marker Plate number

3.4 Pavement Temperature

In general FWD measurements can be carried out over a wide range of surface temperatures. The range for testing flexible pavements should be 10 to 25^0 C. Bituminous bound material behaves in a visco-elastic manner under load and therefore stiffness is temperature dependent. The temperature of the bituminous material must therefore be measured at the time of test and corrected if necessary to a reference temperature. Ideally, FWD testing should be carried out at a temperature, which is as close as possible to the reference temperature. It is not necessary to carry out temperature measurements on thin bituminous pavements such as surfaced dressed granular roads as the thickness of bituminous material is such that it would not have any significant effect on the overall pavement structure.

The temperature of the bituminous material is measured by first drilling a hole in the bituminous layer and inserting a temperature probe into this hole. Holes for temperature measurement should be pre drilled at least ten minutes before recording the temperature in order that the heat generated by drilling has time to dissipate. A drop of glycerol or similar fluid can be used to ensure good thermal contact between the temperature probe and the bituminous material. This procedure takes approximately 15 minutes and should be carried out at least every 4 hours during testing.

3.5 Core/Trial Pit Data

An attempt should be made to establish as full a picture as possible of the pavement construction and maintenance history. On recently constructed pavements this information is usually readily available. However, in the case of older less formal pavements this type of information may be more difficult to ascertain. Information relating to layer thickness, materials used, ground conditions, date of opening etc. are of particular interest. Trial pits can be excavated in many cases to determine the type and thickness of the various pavement layers. In cases where trial pits are not possible coring can be used as a means of determining the thickness of the bituminous bound layers, particularly in Urban areas. Laboratory test can also be carried out on the pavement materials and subgrade soil in order to assess existing ground conditions. Information obtained on the pavement constituents is useful in the later analysis of the FWD deflection data.

4. Presentation and Interpretation of FWD Deflection

4.1 Normalisation of deflections to standard load

The actual peak load achieved during a FWD test will depend on the reaction of the pavement to the load application. The normalising of deflections to standard load makes the comparison of deflections possible. The deflections are normalised to 40 kN target load by linear extrapolation. This means that the deflections are multiplied by the factor ($p_{target}/p_{measured}$). The contact pressure equivalent of the target load (40 kN) on a 300-mm diameter plate is 566 kPa. For example, if the deflections of a specific drop are due to a 570 kPa load, then the measured deflections are multiplied by 566/570 = 0.993 to give normalised deflections.

4.2 Deflection Parameters

There are a number of different ways of presenting FWD deflection data. One useful method of deflection analysis is to plot more than one deflection parameter against distance on the same graph. These plots may also contain marker information, which can be used to identify features along the test sections (e.g. changes in construction, bridges etc.). An example of such a plot is shown in Figure 9.

The first plot shows the central deflection (D1). This plot gives an indication of the overall structural condition of the pavement. The second plot is the Surface Curvature Index(D1-D2), which indicates the condition of the upper pavement layers. Low values of (D1-D2) suggest good load spreading ability of these layers. In cases where this plot takes the same shape as the D1 plot then the upper layers have a large influence on the pavement structural condition. This is usually the case with flexible pavements.

The third plot (D9) relates to the subgrade strength. Low values here indicate a stiff subgrade. In cases where this plot takes the same shape as the D1 plot then

the subgrade layer has a large influence on the pavement structural condition.
The deflection parameters for test lengths can be summarised in tabular form as shown in Table 1.
Some guidance on the relevance of recorded deflection values id given in Tables 2 and 3 for a 40 kN test load.

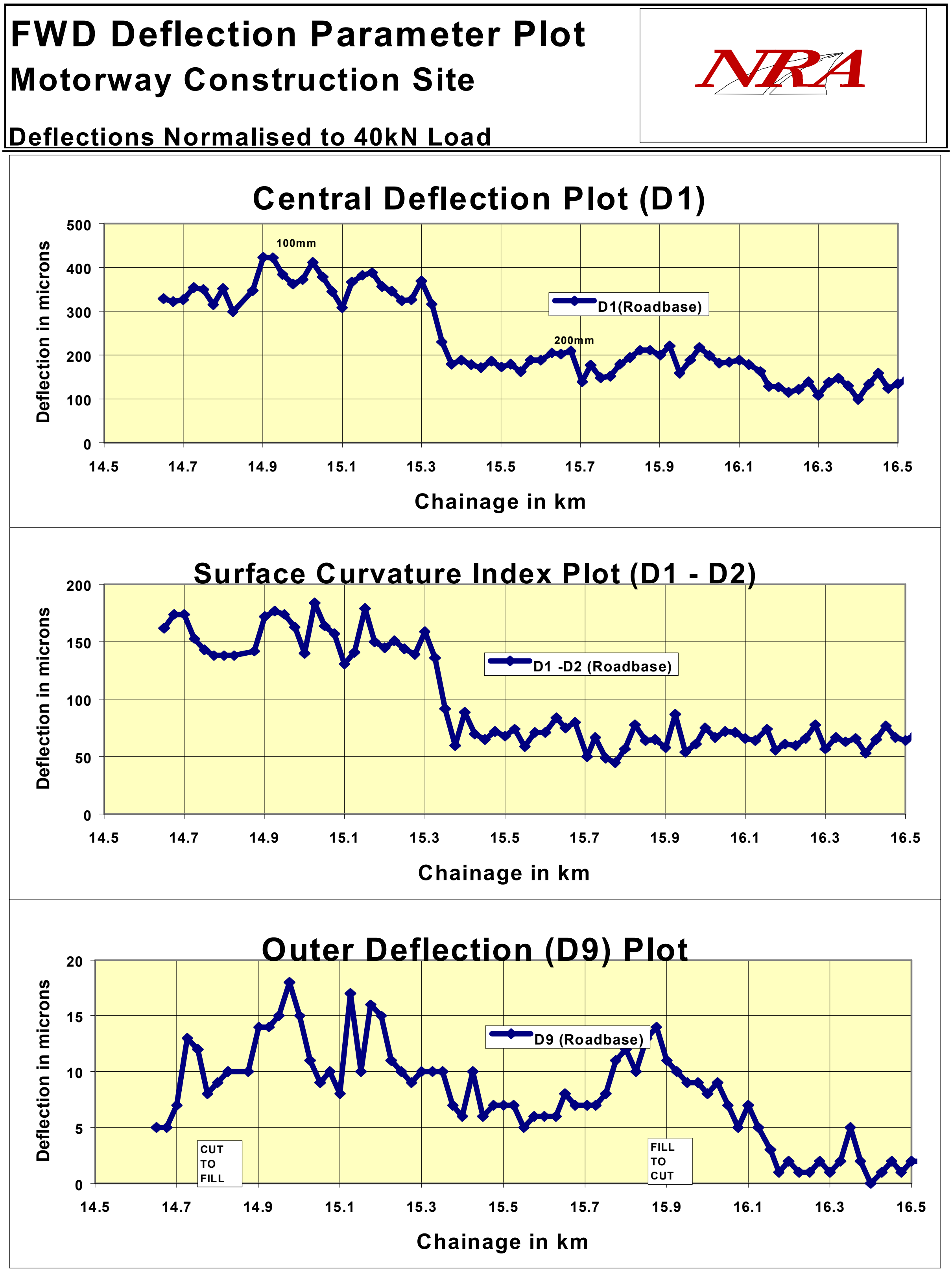

Figure 9: Example of FWD Deflection Plot

Area	Dublin Corporation							
Location	Whitworth road, Clonliff road							
Test Information			Average Deflection Values			Construction		Comments
1	2	3	4	5	6	7	8	9
Test Site	Length in km	# Tests	D1 (Under Load)	D1 - D2 (SCI)	D9 (@2.1 m)	Blacktop Layers (mm)	Granular Layers (mm)	Comments
Whitworth road (EB)	0.8	30	292	92	21	75 - 250	300 - 400*	Some concrete slabs
Whitworth road (WB)	0.8	31	367	118	17	"	"	
Clonliff road (EB)	0.8	33	309	117	17	100 - 140	300 - 400*	Recent trench work
Clonliff road (WB)	0.8	32	291	96	19	"	"	

* Assumed thickness of granular layers

Table 1: Summary of FWD deflection data

National Roads Note All Deflections are normalised to 40kN Load		
D1 Criteria	**SCI Criteria (D1 - D2)**	**Comment**
<100	<40	Very Strong Pavement
100 - 200	40 - 80 Microns	Strong Pavement
200 - 350	80 - 140 Microns	Reasonably Strong - May requir overlay depending on traffic volume
350 - 500	140 - 200 Microns	Moderate Pavement Probably requires overlay depending on traffic volume
500 - 700	200 - 300 Microns	Moderate to weak pavement requiring overlay(possibly granular layer required)
>700	> 300 Microns	Poor Pavement(Granular layer or reconstruction required)

Table 2: Summary of FWD deflection data (Upper Pavement Layers)

Use of FWD on National and Regional Roads Note All Deflections are normalised to 40kN Load	
D9(2,100mm) Criteria	**Comment**
<10	Very Stiff Subgrade
10 - 20	Stiff Subgrade
20 - 30	Stiff to Moderate Subgrade
30 - 40	Moderate to Weak Subgrade
40 - 50	Weak Subgrade
>50	Very Weak Subgrade

Table 3: Summary of FWD deflection data (Subgrade Reaction)

4.3 Summary of FWD Deflections on Irish Pavements

In order to assess the bearing capacity of any pavement, the deflections and other relevant data must be analysed as discussed throughout this document. In order to give an overall comparison of a series of pavement constructions the average central deflection (under the load) has been plotted against thickness of bituminous bound material for a range of road projects. The results are shown in Figure 10. Both new and existing pavements have been included for comparison.

In this graph, a band of one standard deviation either side of the average deflection value for the new pavements tested has been included. This is done so as to give an expected range of deflections for new pavements. It is clear from this graph that pavements with relatively thin bituminous bound thickness (approximately 100 mm) have the most variation after time in service. It appears that pavements that are well constructed initially with thick bituminous bound thickness have tended to maintain low deflection values.

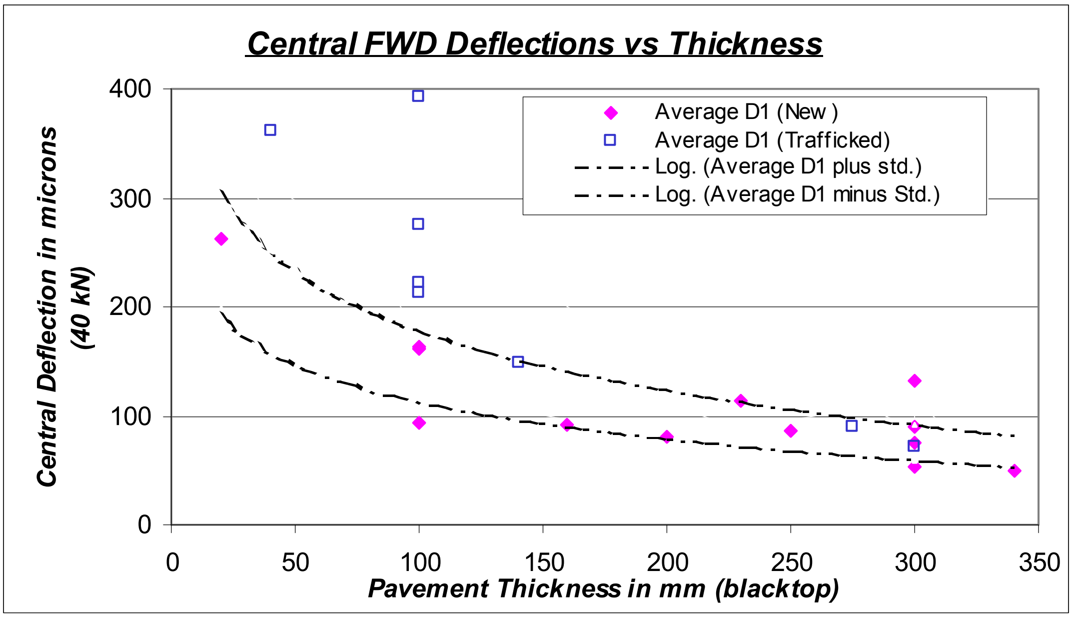

Figure 10: Plot of central deflections versus Blacktop thickness

4.4 Subdivision into homogeneous subsections

Subdivision of a road section may be carried out for a number of reasons and using a variety of techniques. Within a given road section, the measured deflections on one part of the section are often significantly higher or lower than those measured on another part. In this case, it is desirable to divide the main section into subsections, each with a significantly different load bearing behaviour.

A homogeneous subsection is a part of the road in which the measured deflection bowls have approximately the same magnitude and where it is not possible to subdivide it into subsections with significantly different behaviour.

Along with visual assessment of deflection plots, there are several statistical techniques available to divide a series of data into homogeneous parts. One of these techniques is the cumulative sum method. With plots of the cumulative sums of the deviations from the mean of the deflections against test point it is possible to discern these subsections. The cumulative sum is calculated in the following way:

$$S_1 = x_1 - x_m$$

$$S_2 = x_2 - x_m + S_1$$

$$S_i = x_i - x_m + S_{i-1}$$

where x_i is deflection measured at test point i

x_m mean deflection of each main section

S_I cumulative sum of the deviations from the mean deflection at test point i

Using the cumulative sums, the extent to which the measured deflections on a certain part of a road section are different from the mean deflection of the whole section can easily be determined. Changes in slope of the line connecting all cumulative sum values will indicate inhomogeneity.

When continuous information on layer thickness is available, this information can be used for the subdivision of the project into homogeneous subsections. This data can be obtained using Ground Penetrating Radar (GPR), with pointwise information of layer thickness from core samples for calibration purposes.

5. Estimation of is situ layer moduli

5.1 Surface Modulus Plot

In order to obtain an impression of the stiffness of the pavement layers a face modulus plot can be constructed. Such a plot gives an indication of the stiffness at different equivalent depths.

The equivalent thickness of the layers above layer No. n can be calculated from(1) :

$$h_e = \sum_i f_i * h_i * \sqrt[3]{\frac{E_i}{E_m}},$$

where h_e is equivalent depth, mm

f_i	factor, f = 0.8 - 1.0, depending on the modular ratio, thickness and number of layers in the structure
h_i	thickness of layer i, mm
E_i	modulus of layer i, MN/m^2
E_m	modulus of , MN/m^2

This calculation is based on a modification of the original theory of Odemark.

The surface modulus at the top (equivalent thickness= 0 mm) is calculated as:

$$E_0 = \left[\frac{2*\left(1-\nu^2\right)*\sigma_0*a}{d_r}\right]$$

The surface modulus at the equivalent depth $h_e r$ (> 2a) can be calculated from:

$$E_0 = \left[\frac{\left(1-\nu^2\right)*\sigma_0*a^2}{r*d_r}\right]$$

where E_o is the surface modulus at the centre of loading plate

$E_o(r)$ the surface modulus at a distance r (MPa)

ν Poisson's ratio

σ_0 contact pressure under the loading plate (kPa)

a radius of the loading plate (mm)

r distance from sensor to loading centre (mm)

d_r deflection at distance r (mm)

Figure 11 shows two examples of a 'surface modulus' plot. Figure 11a shows an increasing surface modulus with decreasing equivalent depth. This means that the stiffness modulus of the lower layers is less than that of the upper layers. The stiffness of the subgrade will be around 100 MPa. Figure 11b shows a pavement that has a ‘soft’ interlayer between the upper layers and the subgrade. The stiffness of the subgrade is about 300 MPa in this example and the stiffness of the 'soft' interlayer will be approximately 150 MPa.

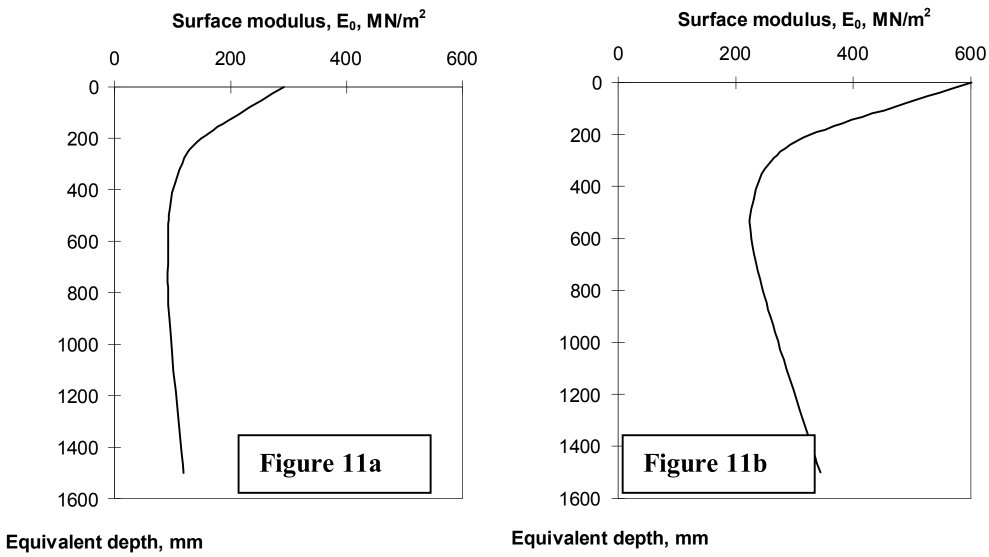

Figure 11a,b. Examples of surface moduli plots.

5.2 Backcalculation of Layer Moduli

The insitu stiffness moduli of the constituent layers can be used to assess the bearing capacity of a pavement. Pavement layer moduli values can be estimated from FWD deflections using a number of methods. Most methods use an iterative process or a database method to reduce the error between the measured and calculated deflections. This process is referred to as "Back-Analysis". There is a wide range of programs available to carry out this analysis. A straightforward linear elastic approach is generally favoured in routine FWD analysis.

5.2.3.1 Bowl matching by manual iteration

In this method, the stiffness is changed using engineering judgement. The back-calculation is begun by making a surface modulus plot, then calculating the subgrade modulus, then the granular modulus and finally the bituminous bound layer modulus. These values can then be manually altered in an iterative manner until predicted and measured deflections match acceptably.

5.2.3.2 Bowl matching by automatic iteration

This method involves forward calculation using an iterative approach. In this system, theoretical deflections are calculated for a set of layer moduli which may or may not be user defined (seed moduli). These layer moduli are then adjusted in an iterative manner until the error between the measured and calculated deflections is sufficiently small. The acceptable error can usually be set by the user. A maximum number of iterations can usually be set also to account for situations where solutions are impossible.

5.2.3.3 Bowl matching by interpretation of bowl database

This approach involves the generation of a database containing a large number of deflection bowls. A set of seed moduli or upper and lower bounds are used as input for the initial database. The measured deflection bowls are then compared to those in the database in order to reduce the error between the measured and calculated deflections. This is usually done either by regression or interpolation techniques. The acceptable accuracy can usually be user defined.

Different programs can handle various numbers of layers usually up to four or five. Most programs tend to work best however when the number of layers is restricted to three. Therefore the modelling of pavements will often require that layers of similar stiffness behaviour be grouped together in order to reduce the overall number of layers. A three-layer structure is shown in Figure 12. Some programs recommend that modular ratios be set in the case of more than three layers. This method can be used in cases where there are two distinct granular layers with different stiffness values. Generally, it is recommended that the model should contain only one stiff layer(bituminous bound) and that moduli decrease significantly with depth(an Ei/Ei+1 ratio of greater than two is sometimes recommended).

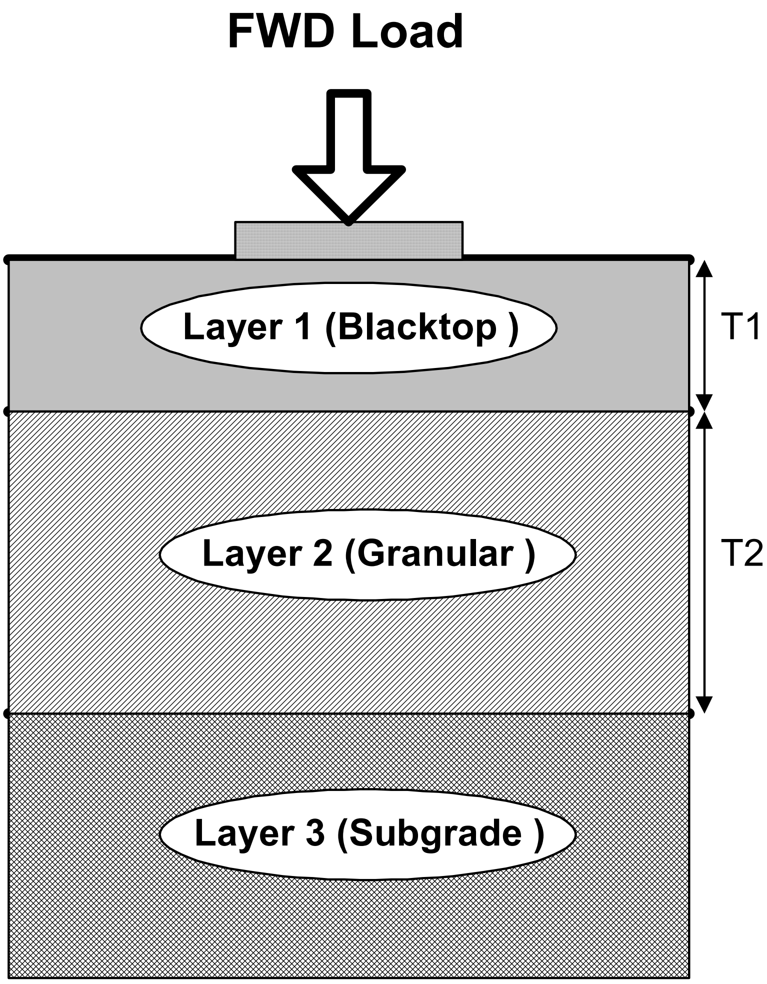

Figure 12: Three Layer Pavement Model

5.1 Normalisation of Pavement Temperatures

The method used for measuring pavement temperatures is described in 3.3. The stiffness of the bituminous bound layers depends on both the test temperature and the loading time. The loading time will be constant for a given FWD device. However, in order to compare deflections/layer moduli they should be normalised to a standard temperature. This will usually be the design temperature for the country or region.

The stiffness moduli of the various layers can be calculated from the measured deflections and the bituminous bound layer stiffness then normalised. There are a number of normalisation methods available(ELMOD etc), some of which are contained within backcalculation packages. An example of three such temperature stiffness relationships(4,5,6) is shown in Figure 13 for a reference temperature of 20 ^{0}C.

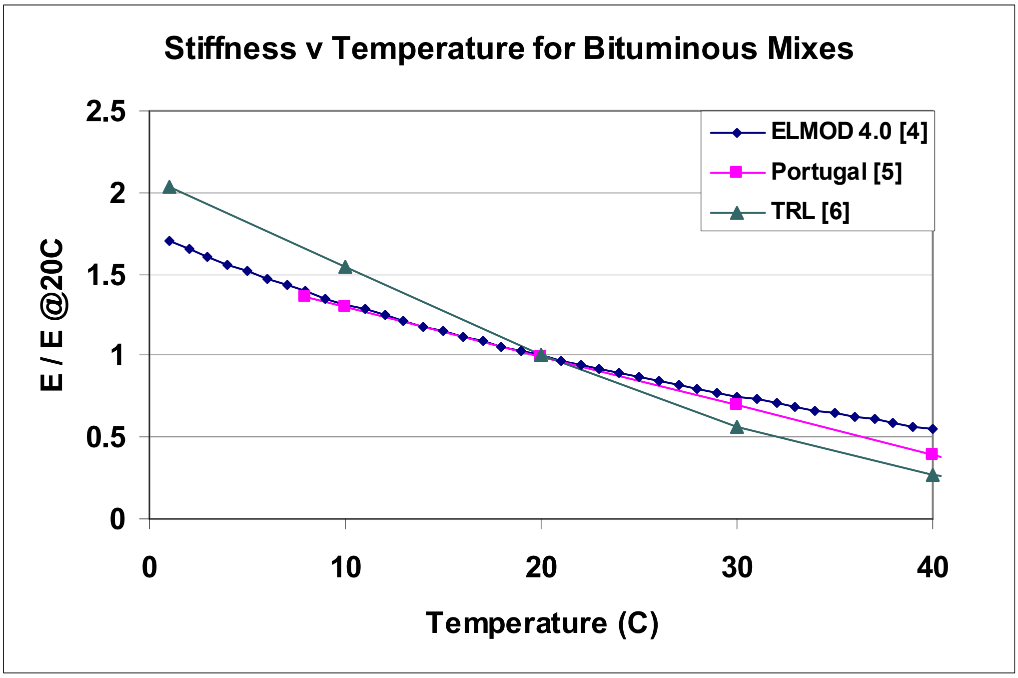

Figure 13: Stiffness versus Temperature relationships

5.4.1.2 Pavement Modelling

For calculation of stiffness moduli it is usually recommended that the thickness of the bituminous bound layer be at least half the radius of the FWD loading plate. In cases where this criterion is not met, a realistic stiffness value based on temperature and degree of cracking is usually assumed for thin layers. It is generally recommended also that the thickness of layers increase significantly with depth.

It is very important that the layer thickness information be as accurate as possible. There are a variety of methods available to measure layer thickness including road construction information, coring, trial pits, Ground Penetrating

Radar(GPR) etc. The type of method used to obtain layer thickness will often be governed by the particular site conditions.

The existence of a stiff layer close to the pavement surface will have a large influence on the calculated layer moduli. Some programs attempt to take this into account when calculating layer moduli. The estimated depth to a stiff layer can be calculated from the shape of the deflection bowl or be user defined. Once the depth to the stiff layer has been calculated the pavement can be modelled as having a fixed bottom boundary.

The upper layer in flexible pavements will usually be a bituminous bound layer. Bituminous bound materials are visco-elastic and so stiffness is a function of a number of factors including loading time and test temperature. The stiffness of a bituminous material can be measured in the laboratory by a variety of methods. One method is to carry out indirect tensile tests on cores cut from the road surface. Great care must be taken when comparing these results with those from FWD deflections due to the visco-elastic nature of the material.

Granular mixes are sometimes stress-dependent and therefore the measured stiffness is dependent on the applied stress. The temperature of granular materials does not generally affect stiffness except in the case of freezing temperatures. Moisture content usually has a large affect on the measured stiffness of these materials. Some granular materials such as limestone can undergo cementing actions, which also have a large effect on material stiffness.

Many subgrade soils are also stress dependent. As in the case of granular materials the measured stiffness will be greatly influenced by the moisture content present at the time of test. Some work has been carried out to relate soil stiffness to other well-known parameters such as CBR(7).

Table 4 contains expected stiffness values and Poisson's ratios for a range of road making materials. The estimated stiffness values may also be plotted against distance as shown in Figure 14. The data in this figure was produced using the ELMOD[4] backcalculation package using bowl matching.

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Material	Range of Stiffness (MPa)	Poisson's Ratio
Hot Rolled Asphalt Wearing Course	4500 - 7500	0.4
Dense Bitumen Macadam Basecourse	4500 - 7500	0.4
Hot Rolled Asphalt Roadbase	8000 - 10000	0.4
Dense Bitumen Macadam Roadbase	7000 - 10000	0.4
Dense Bitumen Macadam 50pen Roadbase	10000 - 13000	0.4
Heavy Duty Macadam Roadbase	11000 - 15000	0.4
Concrete	30000 - 70000	0.2
Cement Bound Material (intact)	10000 - 30000	0.2
Cement Bound Material (primary cracking)	5000 - 15000	0.2
Cement Bound Material (primary and secondary cracking)	500 - 5000	0.3
Granular Base (no cementing action)	200 - 500	0.3
Granular Base (with cementing)	300 - 2000	0.3
Granular Sub-base	50 - 200	0.3
Rockfill	100 - 400	0.3
Clay subgrade	30 - 150	0.4
Blocks / Pavers	500 - 1000	0.3

Table 4: Expected Stiffness values for Pavement materials

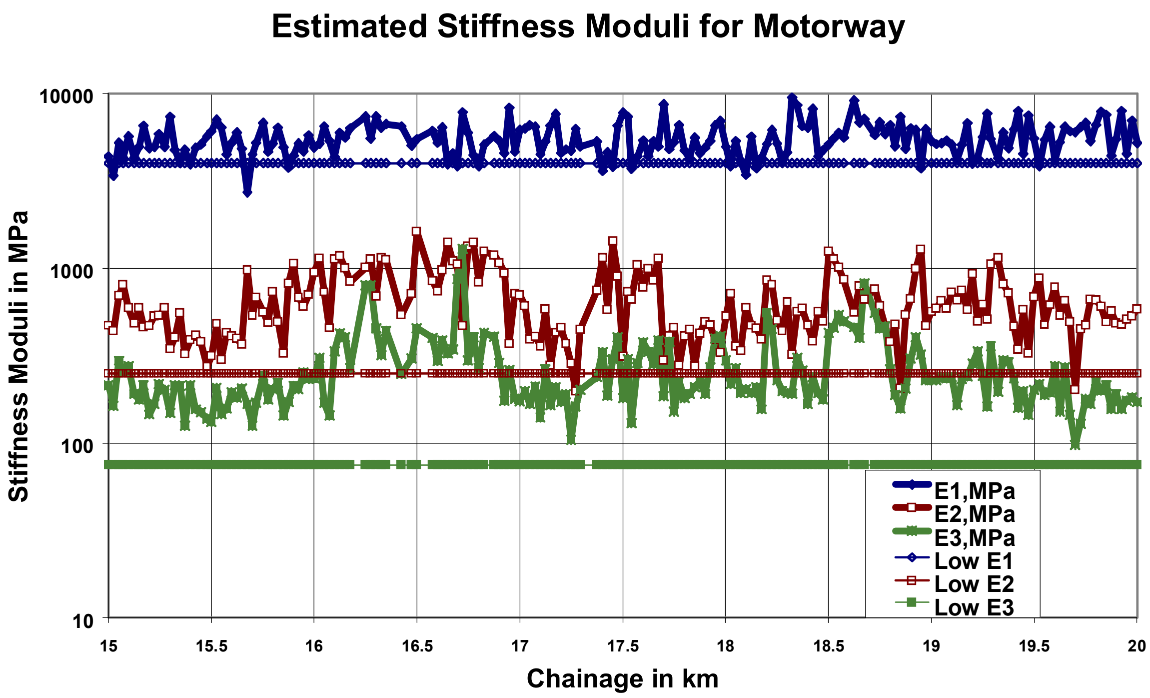

Figure 14: Estimated Stiffness Values for Motorway[4]

5.4.1.7 Limitations of modelling

Great care must always be used when modelling pavement structures. All estimated stiffness values are based on inputted parameters such as layer thickness and type. Therefore errors in the accuracy of inputted information will lead to errors in the output data.

Some pavement conditions can also be difficult to model effectively. One example of this is leanmix concrete or cemented subbase material that has been overlaid with thin bituminous layers. Very often these type of materials crack at irregular intervals due to variations in material properties. Modelling of these type of pavements is therefore difficult due to the inhomogenity of the pavement structure.

6. Overlay design

The addition of a new structural layer to an old or distressed pavement is a widely used method of prolonging the service life of a pavement. This is often done by overlay with new bituminous bound material. A new overlay will reduce the stresses in the existing pavement and will also seal small cracks in the surface, thus reducing water ingress into the pavement layers.

The two most important overlay design parameters are the design traffic volume and the design overlay material. Traffic can be estimated in a number of ways. The LR1132[7] method uses a formula based on the initial daily traffic flow, expected growth rate over the design life and the proportion of commercial vehicles using the slow lane. The method outlined in COST 333[3] also takes into account such factors as width of driving lane, slope etc.

The design modulus and fatigue characteristics of the overlay material are also used as input into the overlay design procedure. It is important that the design characteristics of the overlay material are similar to that which will ultimately be used on the road.

The average and 85th Percentile overlay values are usually calculated. The 85th Percentile value is usually used for overlay on National Roads. The calculated overlay values can be plotted to give a visual indication of the range of overlay requirement. In many cases remedial action will be required prior to the use of an overlay carpet. An example of an overlay design plot is shown in Figure 15.

A series of overlay design calculations were carried out on a motorway construction site using the overlay design method in ELMOD[4]. Overlay design calculations were carried out for a range of design traffic loading and on a range of existing pavement thickness. The design characteristics of the overlay material are similar to those of dense bitumen macadam basecourse material[8]. The results of this exercise are shown in Table 5. These overlay values should be taken as examples only as the actual overlay design values will always depend on the construction and subgrade soil conditions present along a particular test length. In this case, there were substantial depths of granular material (capping and CL. 804) present and the construction was supervised by a full Resident Engineering staff.

The average estimated stiffness values and overlay design calculations can be summarised for a particular project as shown in Table 6.

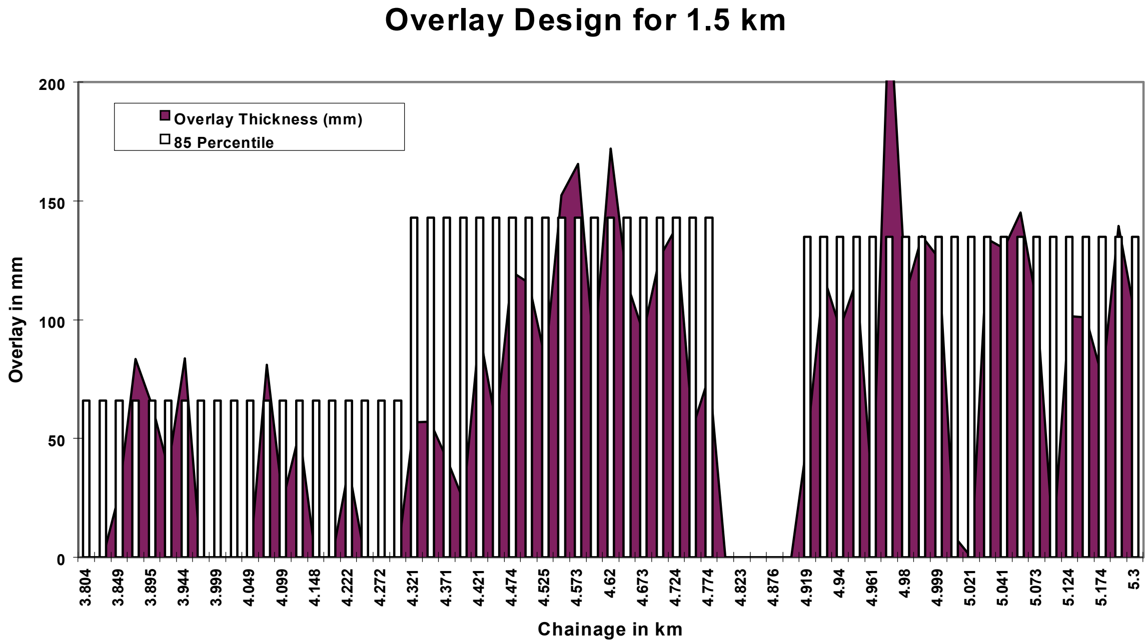

Figure 15: Example of Overlay Design Plot

	Overlay Design Calculations for Motorway Construction site							
				Overlay design Thickness for Traffic Load				
Existing Thickness of Blacktop	Max Deflection D1 (40kN Load)	SCI(D1 - D2)	D9	1 MSA	3.5 MSA	12 MSA	24 MSA	40 MSA
75	450	227	9	*40*	*70*	*120*	*145*	*165*
75	400	188	6	*20*	*60*	*110*	*135*	*155*
100	350	160	10	*15*	*40*	*90*	*120*	*140*
100	300	126	9	*15*	*45*	*95*	*120*	*145*
100	250	102	9	*0*	*20*	*70*	*90*	*120*
200	200	68	8	*0*	*0*	*30*	*60*	*80*
200	150	68	7	*0*	*0*	*0*	*0*	*15*
300	100	34	5	*0*	*0*	*0*	*0*	*0*
300	50	25	2	*0*	*0*	*0*	*0*	*0*

Table 5: Overlay design values for Motorway construction site

Area	Dublin Corporation							
Location	Whitworth road, Clonliff road							
Test Information			Average Estimated Moduli			Overlay Design		Comments
1	2	3	4	5	6	7	8	9
Test Site	Length in km	# Tests	E1 (Bituminous @ 20C)	E2 (Granular)	E3 (Soil)	Design MSA	85 Percentile Overlay	Comments
Whitworth road (EB)	0.8	30	8,700	610	70	30	*40*	Some concrete slabs
Whitworth road (WB)	0.8	31	2,900	340	40	"	*40*	
Clonliff road (EB)	0.8	33	3,700	400	100	20	*50*	
Clonliff road (WB)	0.8	32	6,000	400	90	"	*30*	

Table 6: Example of summary table for stiffness and overlay values

7. Minimum Information to be Supplied from FWD Survey

The following information should be supplied as a minimum requirement for an FWD survey report;

1. Copies of the Calibration and Correlation certificates for the FWD device should be available on request (Appendices A, B).
2. The relevant data outlined in section 3.3 of this report should be supplied per test length.
3. Recorded deflection parameters (normalised to standard load) plotted against distance for each test length.
4. Summary of deflection parameters and construction details for each test length or homogeneous sub section.
5. Summary of estimated layer moduli values and overlay design values (if any) for each test length or homogenous sub section. The methods and assumptions used to produce the stiffness and overlay design values should be outlined.
6. All deflection (.F20), layer moduli, Overlay data should be made available to the client in digital format and on paper if requested.
7. The FWD survey report should contain advice on the relevance of the deflection results and the most appropriate remedial measures to be undertaken.

8. References

1. FEHRL (1996). Harmonisation of the Use of the Falling Weight Deflectometer on Pavements (Part 1), FEHRL Report 1996/1, Crowthorne: Transport Research Laboratory.
2. Raithby, R.D., Sterling, A.B., Some Effects of Loading History on the Fatigue Performance of Rolled Asphalt, TRRL Report LR469, Transport and Road Research Laboratory, Crowthorne, 1972.
3. COST 333, Development of New Bituminous Pavement Design Methods, Final Report of Action, European Commission Directorate General Transport, 1999
4. ELMOD Backcalculation and Overlay Design Computer Package, Dynatest.
5. Research Document (Unpublished) from Portugal.
6. Research Document (Unpublished) from TRL, Crowthorne, UK.
7. Powel, W.D, Potter, J.F., Mayhew, H.C, Nunn, M.E*, LR 1132 The Structural Design of Bituminous Roads*, 1984, TRL, Crowthorne, Berkshire, UK.
8. British Standards Institution, BS 4987: Part 1: 1993, Coated Macadams for Roads and Other Paved Areas, Part 1: Specification for Constituent Materials and for Mixtures

Bonneagar Iompair Éireann
Transport Infrastructure Ireland

Ionad Ghnó Gheata na Páirce,
Stráid Gheata na Páirce,
Baile Átha Cliath 8, Éire

Parkgate Business Centre,
Parkgate Street,
Dublin 8, Ireland

www.tii.ie

info@tii.ie

+353 (01) 646 3600

+353 (01) 646 3601