TECHNICAL GUIDE
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Deflection testing of earthwork and pavement layers

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Deflection testing of earthwork and pavement layers

Preface

This guide covers the test methods T160, T177, T191, T198 and T199 and does not cover the interpretation of deflection data.

1. Introduction

Deflection testing is a very important and a non-destructive tool for evaluating pavement layers. There are a number of different methods of determining pavement deflection depending on the type of information required.

Deflection testing can estimate the remaining life of a pavement, detect soft or wet areas of a new formation or provide the basis for determining areas of existing pavement that require rehabilitation.

Note that deflection surveys are moisture sensitive and if testing after prolonged periods of wet weather the results will be higher than if testing in drought conditions. Deflection testing will only give an indication of the formation or pavement stiffness at the particular location at the particular time of testing.

Roads and Maritime specifications require regular deflection testing during construction. Limiting the deflection of the formation under the pavement limits the amount of deflection that must be withstood by the pavement in service. If deflections are too high for a particular pavement design premature distress may occur.

There are three methods commonly used for collecting deflection data namely:

- The portable beam. A labour intensive but cost effective means of testing conformance on new construction or testing short lengths of existing roads to determine areas requiring rehabilitation treatment (see Figure 1). Generally tested at 10 m intervals.
- Deflectograph. This device can provide a reading in both OWP and IWP every 4 m (see Figure 2). Commonly used for surveying existing roads in long lengths. The deflectograph tests the road at 3 to 4 km/h.
- Falling Weight Deflectometer (FWD). The FWD is used to estimate the insitu stiffness of pavement and subgrade layers (see Figure 3). The FWD is a device that applies a dynamic load to the pavement surface, similar in magnitude and duration to that of a single moving wheel load. The response of the pavement is measured in terms of vertical deflection, over a given area using seismometers. The apparatus is generally trailer mounted which allows it to move onto a site, test and move off a site very quickly.

When testing on public roads the above three methods all require traffic control.

A new device called the Traffic Speed Deflectograph (TSD) is used in Australia, but is current use is limited to road network surveys.

It is noted in Figure 1 that the concrete ballast block has been sealed with a grey paint to prevent moisture absorption that would increase the rear axle load and the rear mud flaps have been raised to allow ease of positioning of beam tip.

The selection of a particular method of collecting deflection data is usually based on the reason for requiring the data and the costs associated with the deflection survey.

Figure 1: Example of a purpose built Portable Beam truck

Figure 2: View of deflectograph

Figure 3: View of FWD with the geophones lowered onto the road surface

It is noted that the beam truck has a short overhang of the tray at the rear axle to allow ease and safe access to beaming equipment.

2. Definitions

The following list of definitions are used in this guide and does not represent a complete list of soil testing definitions.

Deflection - Is the degree to which a road formation is displaced under a load.

Deflection Bowl - Is a representation of the shape of the deformation of the pavement surface caused by a load being applied to the surface.

Maximum Deflection - The measured maximum vertical movement of the pavement.

Curvature - Is an indication of the shape of the Deflection Bowl which is determined by calculating the difference between the maximum deflection and the measured deflection at a point 200 mm away. The curvature of the deflected pavement gives an indication of the fatigue performance of the pavement

3. Common Deflection Test Methods

3.1 T160 – Deflection Measurement (Portable Beam) Test Methods

This test procedure covers the determination of the rebound deflection of a pavement under a standard wheel load and tyre pressure. The Benkelman (portable) Beam apparatus is a convenient, cost effective and accurate device used for measuring the deflection of flexible pavements under moving wheel loads. The beam is commonly used as a tool for evaluating compaction and moisture content in new construction projects.

The Benkelman Beam (Figure 4) measuring process commences between the wheels of a stationary truck and records the latter half of the deflection bowl as the truck moves away. The full rebound of the pavement can be assessed from continuously reading the dial gauge after the truck has moved.

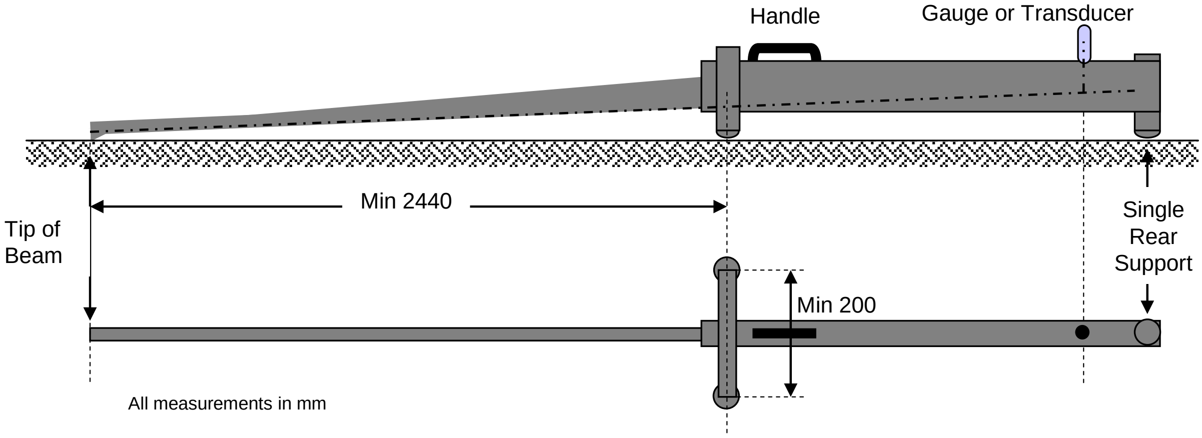

Figure 4: Diagram (elevation & plan) of a typical Benkelman (portable) Beam

Portable beams work by measuring the rebound deflection of the road, as the truck loads the formation, moves off and the beam measures the road returning to the unloaded position as shown in Figure 5.

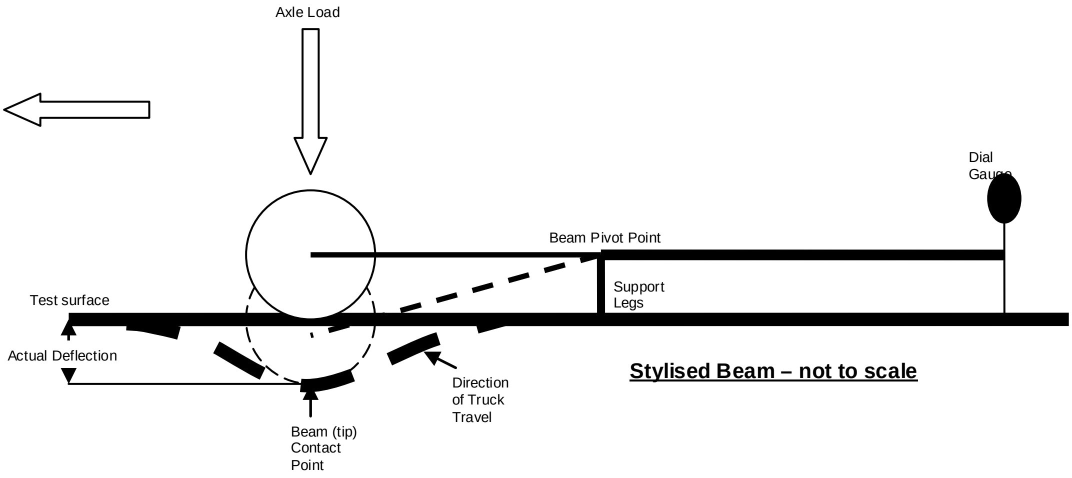

Figure 5: Schematic diagram of a Portable Beam during operation

Portable deflection beams come in a variety of designs and styles, some of which do not conform to Roads and Maritime Services requirements. The requirements of a typical Benkelman Beam as shown in Figure 4 are listed in test methods T160 and T199. Beams that do not conform must not be used on Roads and Maritime Services projects.

The basic design of the beams requires a conversion of the raw data to actual deflection in millimetres. This conversion is due to the beam having a length ratio, from the tip to the pivot point (legs) and the pivot point to the rear support, where the dial gauge is seated. This conversion ratio is usually either 2:1 or 3:1. The examples in Figure 6 shows both beams.

Figure 6: Examples of a 2:1 beam (top) and a 3:1 beam (bottom)

The equipment required for Benkelman Beam testing is;

- A Benkelman beam that meets the minimum requirements of T160.
- A truck with a single rear axle and dual back wheels. T160 details the type of tyre and the allowable tyre pressure and does not allow the use of lugged type tyres. Figure 7 shows suitable rib and block tyres and unsuitable rib-lug and lug type tyres. The tyre must provide a smooth and even distribution of load beneath the tyre footprint. A lugged tyre produces point loads and is considered unsuitable for use. The truck must have an 8.2 t ± 0.15 t rear axle load with, this load being evenly distributed over both sets of rear wheels and remain within these tolerances when ever testing. Purpose built trucks generally have a concrete slab or steel weights as their load to achieve the test load. Water carts are not permissible as the load can change when accelerating or braking.

Type	Rib	Block	Rib-Lug	Lug
Pattern				
Profile	Grooves flows along the circumference of a tire.	Patterns in which individual blocks are arranged.	Combination of rib and lug patterns.	Grooves flows in a lateral direction.

Suitable tyres Unsuitable Tyres

Figure 7: Suitable rib and block tyres and unsuitable rib-lug and lug tyres

- A system of accurately measuring the progressive distance of readings (i.e. 200 mm, 600 mm, 900 mm, 2700 mm and 9 m). This is sometimes measured electronically but usually with a knotted string line or thin rope. Either system conforms providing checks have been made prior to use.
- The tip of the beam usually has a small wheel to allow for ease of positioning between the dual wheels.
- The majority of beams use a dial gauge for measuring deflection and this involves manually recording the measurements. Some use a Linear Voltage Displacement Transducer (LVDT) attached to a data logger, reducing the risk of human error. Both systems are compliant providing they conform to the calibration requirements of the test method.
- The dial gauge must have a vibratory attachment to prevent the dial gauge stem sticking due to dust.
- If measuring deflection on asphalt surfaces the temperature of the asphalt is required for deflection adjustments. Warmer asphalt surfaces are more 'soft' than cold asphalt and this has to be adjusted when evaluating deflection data. A hole in the AC must be made to allow the temperature to be taken approximately 30 mm below the surface. This hole should be filled with light oil (e.g. Glycerol) and the thermometer allowed to stabilise before recording the temperature. The asphalt temperature must be taken prior to the start of testing and then at least every hour.

At the test location it is important that the area of contact of the beam: tip, two legs & dial gauge, are free of any loose material. This material could move during the test giving a false and usually high reading. It is also very important that the four points of contact are the only places the beam touches the ground. Note that the tip of the beam is where deflection occurs not at the dial gauge end where the movement is registered.

A manual beam must be placed so that the tip of the beam is positioned between the dual wheels and in the centre of the wheel contact. The beam must never make contact with the tyres.

The dial gauge is then positioned so that it has enough travel to allow for high readings. It defeats the purpose of testing if the dial gauge is set up to only have 0.5 mm of travel if deflection is greater than this.

The dial gauge is now zeroed or the reading recorded as a base line reading.

The technician remains stationary whilst the test is taken (< 30 s) of the test and must be able to easily read the dial gauge while allowing the string line to pass through the palm of the hand. As each knot passes through the palm of the hand the technician reads the dial gauge. Generally some one else acts as a scribe, recording the readings as spoken by the technician taking the readings.

<table>
<tr><td colspan="3">Section Represented: Subbase, 2.00 – 2.50 km EBL</td><td colspan="4">Tyre Gauge No: 8713</td><td colspan="3">Date Tested: 28-4-12</td></tr>
<tr><td colspan="3">Weight of Rear Axle (weigh bridge): 8.18 t</td><td colspan="7">Tyre Pressure – LHS: 750/755 RHS: 735/745</td></tr>
<tr><td colspan="2">Beam factor : 3:1</td><td colspan="6">Temperature (°C) – Air: N.A. Road: N.A.</td><td colspan="2">Thermometer No: N.A.</td></tr>
<tr><td rowspan="2">Chainage (m)</td><td rowspan="2">Lane</td><td rowspan="2">Wheel path</td><td colspan="5">Dial gauge Reading (mm)</td><td rowspan="2">Maximum Deflection (mm)</td><td rowspan="2">Remarks</td></tr>
<tr><td>200 mm</td><td>600 mm</td><td>900 mm</td><td>2.7 m</td><td>9 m</td></tr>
<tr><td>2.150</td><td>EBL</td><td>OWP</td><td>0.25</td><td>0.31</td><td>0.35</td><td>0.36</td><td>0.36</td><td>1.08</td><td></td></tr>
<tr><td>2.160</td><td>EBL</td><td>IWP</td><td>0.02</td><td>0.05</td><td>0.06</td><td>0.07</td><td>0.08</td><td>0.24</td><td></td></tr>
<tr><td>2.170</td><td>EBL</td><td>OWP</td><td>0.12</td><td>0.14</td><td>0.16</td><td>0.17</td><td>0.18</td><td>0.54</td><td></td></tr>
<tr><td>2.180</td><td>EBL</td><td>IWP</td><td>0.51</td><td>0.62</td><td>0.68</td><td>0.73</td><td>0.75</td><td>2.25</td><td>Cracking</td></tr>
</table>

Figure 8: Examples of Benkelman Beam data. (3:1 ratio beam)

Although not very common, electronic beams (E-Beams) are available for T160 testing. These beams are nearly identical to a manual portable beam except the dial gauge is replaced with a transducer that automatically logs the deflection values. The benefit of these E-Beams is the accuracy of recording the deflection bowl. As shown in Figure 8, labs can also set up two beams to simultaneously record deflection in both wheel paths.

Beams with electronic data capture have the tip of the beam placed approximately 300 mm forward of the central wheel position to allow more accuracy in recording the maximum deflection.

Figure 9: Example of electronic portable beams extended from the truck

3.2 T177 – Pavement Deflection Measurement (Falling Weight Deflectometer)

A Falling Weight Deflectometer (FWD) is designed to impart a load pulse to the pavement surface which simulates the load produced by a rolling vehicle wheel. The load is produced by dropping a large mass, and transmitted to the pavement through a circular load plate, typically 300 mm in diameter (see Figure 9). A load cell mounted on top of the load plate measures the load imparted to the pavement surface. Geophones are mounted radially from the centre of the load plate to estimate the deformation of the pavement in response to the load. Some typical offsets are 0 mm, 200 mm, 300 mm, 450 mm, 600 mm, 900 mm, 1200 mm and 1500 mm.

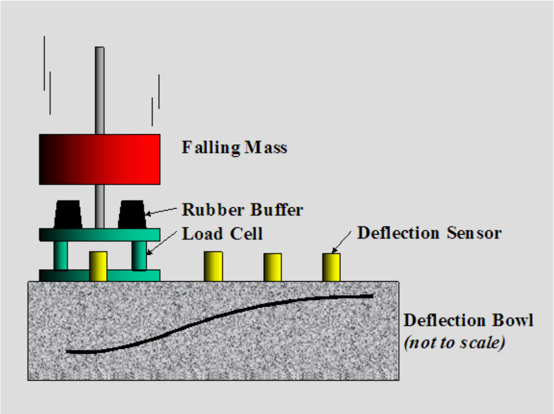

Figure 10: Close up view of the FWD and diagram of deflection bowl

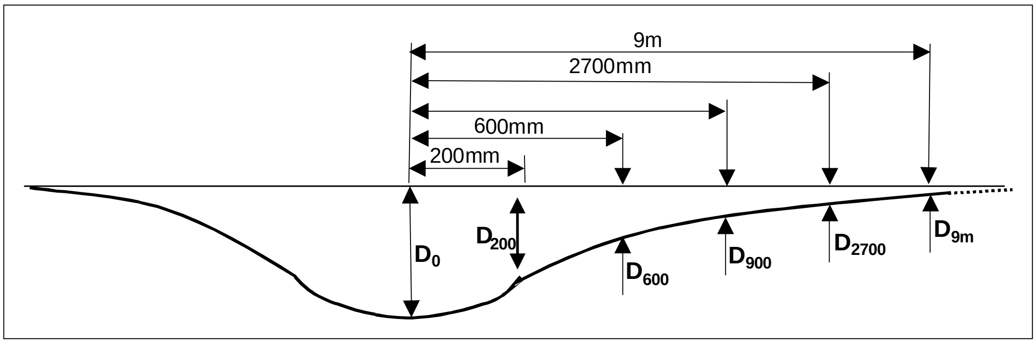

Figure 11: Example of a deflection bowl

The FWD equipment must comply with the requirements of Austroads Test Method AG:AM/T006 and the device must also be equipped with a system to locate itself both longitudinally and laterally on the road. The FWD is not as cost-effective as the other two methods in measuring deflections at closely spaced intervals if this is required to characterise pavements with variable stiffness. FWD readings are frequently taken at 100 m intervals with the assumption that the test site is representative of the section of road.

It is very important that the individual test site is representative of the area of road being tested. There must be no structures, such as trenches, culverts or pits, the test site must also be free of localised defects and loose material.

At the test site the load cell and sensors are lowered to the pavement then an applied stress of 700 kPa corresponding to a load of 50 kN is used. This process is repeated three times, the test loads must not vary more than ± 4% of the target load level and the deflection values recorded must not vary by more than 5% or 5 micron (whichever is greater) for any one sensor. The peak load and geophone sensor readings resulting from the third (final) drop are used as the test result.

The pavement and ambient temperatures must be recorded for each site and this is particularly important if an asphalt surface is being tested. A photograph of the area of test is an excellent idea to record the pavement conditions at the test location.

3.3 T191 – Determination of Deflection and Curvature by Deflectograph

As the deflection bowl using a deflectograph is only 4 m compared to the 9 m bowl of a portable beam, a maximum deflection conversion of 1.2 is used to compare deflectograph readings with those of the portable beam. Figure 12 shows this conversion together with the conversion for FWD, which is very dependant on the thickness of asphalt being tested.

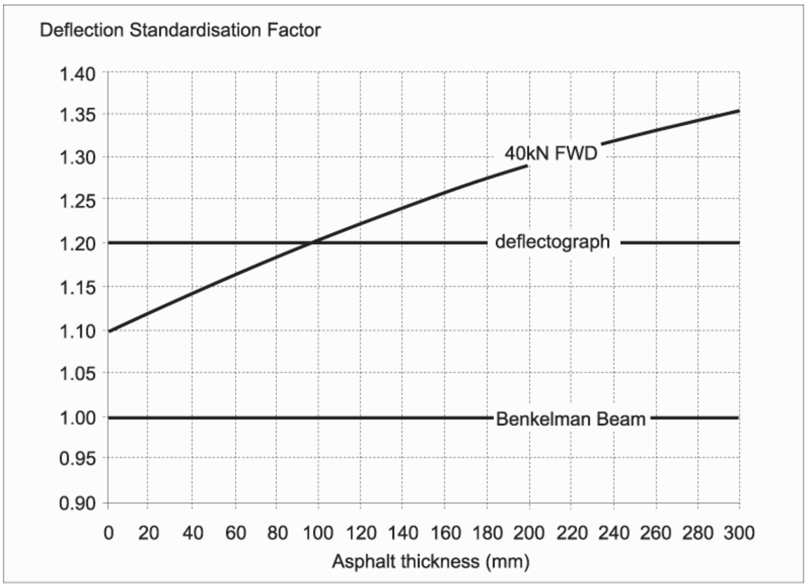

Figure 12: Conversion factors for the three commonly used deflection methods (Source: Austroads Guide to Pavement Technology, Part 5, Appendix E)

Where the Portable Beam measures rebound deflection the Deflectograph measures the actual deflection as the load approaches the tip of the beam. As the deflectograph drives down the road, the rear wheels approach the beams; deflection of the pavement is registered by transducers in the beam housing, and then recorded on a data logger. When the beams pass the centre of the dual wheels (max deflection) a switch is tripped which causes the beam carriage to be dragged forward, released, then the cycle starts again.

DEFLECTOGRAPH DEFLECTION FILE									
DATE:		**8/07/2004**						**TIME:**	**10:48 AM**
OPERATOR:		**#1**							
DRIVER:		**#2**							
RMS DIVISION:		**NSW**							
ROAD NUMBER:		**HW123**						**LANE:**	**E/B K/L**
SURVEY NUMBER:		**Eleventeen**							
STARTED AT:		**DFG START END OF NEW SEAL**							
ENDED AT:		**START OF NEW SEAL (DFG END)**							
Note: B.B.C.F. of 1.2 has been applied to produce adjusted maximum deflection values.									
LEFT	**LEFT**	**LEFT**	**RIGHT**	**RIGHT**	**RIGHT**	**ODO**	**TEMP**	**EVENT**	
MAX	**MAX Adj**	**CURVE**	**MAX**	**MAX Adj**	**CURVE**	**METE R**			
(mm)	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(km)**	**(^{o}C)**		
0.64	0.77	0.20	0.69	0.83	0.24	0.001	25	DFG START (END OF NEW SEAL)	
0.55	0.66	0.19	0.46	0.55	0.18	0.006	25		
0.59	0.71	0.20	0.55	0.66	0.17	0.010	25		
0.60	0.72	0.16	0.48	0.58	0.15	0.014	25		
0.52	0.62	0.20	0.67	0.80	0.28	0.018	25		

Note the maximum deflection data shown in Figure 13 have been adjusted (as per Figure 4) to align them with Portable Beam results.

The deflectograph is an excellent tool to determine areas of sub-standard pavement over long sections of road for example if a section of road earmarked for overlay shows areas of high deflection, these areas should have some type of rehabilitative treatment prior to the overlay.

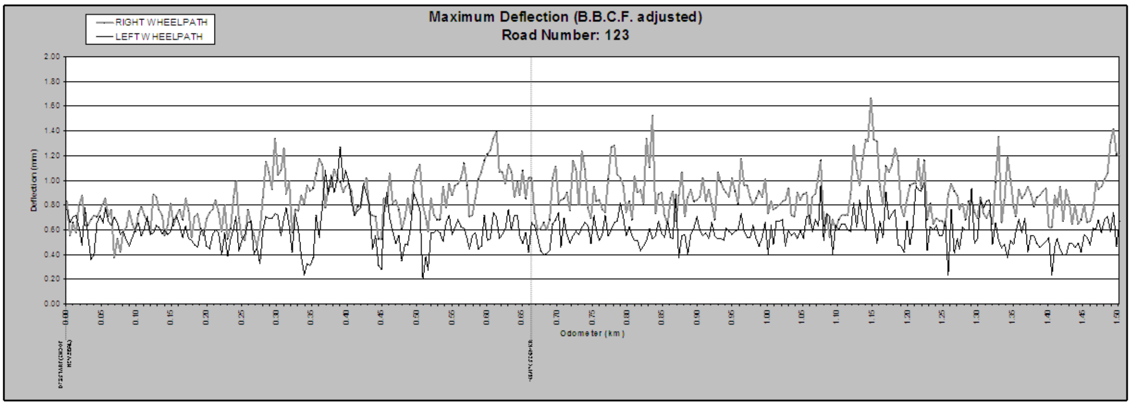

Figure 13: Examples of Deflectograph raw data and associated graph, showing maximum deflection in both wheel paths.

3.4 T198 – Proof Rolling Test

This method sets out a procedure for assessing the stiffness and uniformity of compaction of a road formation during construction, by observing the surface deformation of a layer under a moving heavy roller. Proof rolling is a very useful tool for detecting areas of movement on progressive fill where Portable Beam testing is not required.

The basic equipment required is either a pneumatic tyre static roller of a least 4.5 tonnes per tyre and 600 kPa tyre pressure or a 10,000 litre water tanker containing 10000 litres of water with baffles to minimise water sloshing with a minimum 600 kPa tyre pressure. Other equipment with at least the same rear axle loading as the water tanker may be used if approved by the principal.

Generally the layer being tested has passed compaction testing and then must pass proof rolling before the next layer is placed. If more than 12 hours has passed since compaction was finalised, the lot to be tested must be watered and have at least three passes with a roller prior to proof roll testing.

Prior to testing a rolling pattern must be determined that covers the entire lot being testing and has each roller pass offset laterally by 40% to 50%. This overlap is to ensure all areas of the lot can be assessed.

During testing a technician walks beside the plant looking for perceptible movement, it is generally accepted that an ‘experienced eye’ can detect deflection down to 2 mm. A static smooth steel drum roller may not identify localised soft areas as the rigid drum could bridge these areas and this type of plant must not be used.   Usually the technician paints a mark on the formation at areas that show movement and then at the completion of the testing must make a decision as to the uniformity of the lot and whether there is any perceptible movement.

Figure 14: Proof rolling being carried out using a fully laden gravel truck

Figure 15: Areas marked for rehabilitation after failing proof rolling

3.5 T199 – Deflection testing of road formation

This test method sets out the procedure for determining the stiffness and homogeneity of a road formation using a portable deflection beam by statistically analysing the data from the T160 test.

T199 is designed to assure us that the lot is homogeneous and stable by having consistent and non excessive deflection. It is very important that lots are homogeneous so that they behave as a whole, a lot that has wet areas can exhibit differential shrink and swell characteristics causing problems with overlaying layers.

The testing proceeds as per T160, but to make a valid statistical analysis of the lot being tested there is a requirement of a minimum of twelve tests evenly spaced over the entire lot, generally there will be significantly more (refer to Figure 16)

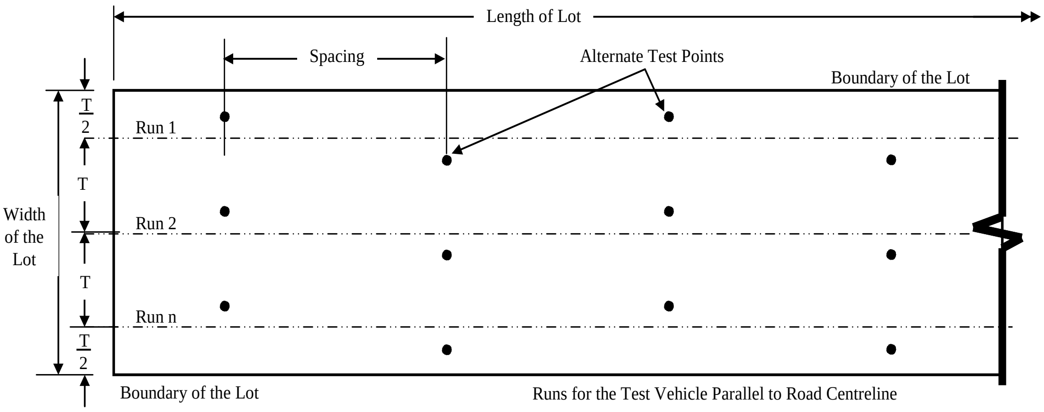

Figure 16: Example sample pattern for test points within a Lot

The spacing must not be more than 10 m, test points must not be within 0.5 m of the boundaries of the lot and runs (T) must be positioned to equally cover the lot, these runs are not to be more than 3.6 m transversely apart. The T199 test is conducted in alternate wheel paths to ensure the lot is adequately covered with test points.

This test method reports two main values, namely the Coefficient of Variation and Deflection.

The Coefficient of Variation (CV) is defined as follows:

$$CV = \frac{SD}{M} \times 100\%$$

Where:

CV	=	Coefficient of Variation for the lot (%)
M	=	Mean of the maximum deflections (mm)
SD	=	Standard Deviation of the maximum deflections (mm)

The Characteristic Deflection (CD) is defined as follows:

$$CD = M + (f \times SD)$$

Where:

CD	=	Characteristic Deflection (mm)
M	=	Mean of the maximum deflections (mm)
f	=	Factor = 1.65
SD	=	Standard Deviation of the maximum deflections (mm)

The Roads and Maritime earthwork specifications R44 requires the Characteristic Deflection to not exceed 1.2 mm, with a standard deviation of less than 0.2 mm. If the Characteristic Deflection does exceed 1.2 mm then the Coefficient of Variation must not exceed 25%.

4. Curvature of the deflection bowl

The curvature function (CF) of a deflection bowl is given by;

$$CF = D_0 - D_{200}$$

Where;

D_0 = maximum deflection (mm) for a test point

D_{200} = the deflection measured at the test point when the test load is 200 mm from the point at which the maximum deflection at the test point was produced (in the direction of travel) (mm)

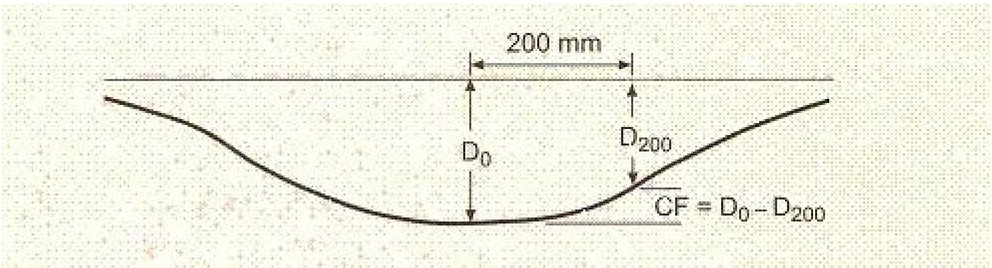

Figure 17: Curvature Function diagram

Be very careful if determining the curvature from Portable Beam readings, the portable beam measures rebound deflection. So the D200 figure in the above equation is not the 200 mm reading as recorded. D200 will actually be the 200 mm reading subtracted from the Maximum Deflection, the beam ratio (2:1 or 3:1) correction must be applied to this calculation.

For Portable Beams;

$CF = (D_{9m} \times BR) – ((D_{9m} \times BR) – (D_{200} \times BR))$

Where;

$D_{9\,m}$ = the reading recorded at 9 m. (The 9 m reading is deemed to be the maximum deflection)

D_{200} = the reading as recorded at 200 mm.

BR = the beam ratio factor.

But this can be further simplified to:

$CF = D_{200} \times BR$

The portable beam reading at 200 mm multiplied by the Beam Ratio factor.

5. Summary

The typical shortcomings associated with deflection testing may be summarised as follows;

- Portable beam string lines can cause problems and often the string line is not taut at the start of the test. The first reading is at 200 mm if the truck has to move and take up the slack before the string line goes through the technicians hand and therefore the accuracy of this first reading is questionable.
- The truck will have moved further than the distance reported.
- The string line is usually held in the hand and it is very important that the hand does not move. Sometimes the zero or 200 mm knot draws the technician’s hand forward. It is advisable for the technician to either lock his elbow into his side or even hook his thumb into his trousers to prevent any movement.
- It is also advisable for the technician to let the string line go gently through his hand to prevent the hand being drawn forward.
- The truck driver should be advised to drive off slowly so the readings can be correctly captured. If driven too fast the technician cannot accurately read the dial gauge.

These issues must be negated, especially if the information is to be used for calculating the Curvature Function. Also,

- The extremities of the lot must be correctly identified so that the beam survey fully covers the area.
- FWD sites must be carefully selected so that they represent the area being surveyed.
- When proof rolling there is a tendency to following the revolving wheel rather than the pavement. This can be alleviated by standing a few metres to the side of the wheel.

6. References

General

Austroads (2011) Guide to pavement technology: part 5: pavement evaluation and treatment design AGPT05/11 Austroads, Sydney NSW

Austroads Test Methods

Austroads (2011) Pavement deflection measurement with a falling weight deflectometer (FWD) AG:AM/T006, Austroads, Sydney NSW

Roads and Maritime Test Methods

Roads and Maritime Services (2012) Deflection measurement (Portable beam) T160, Roads and Maritime Services, North Sydney NSW

Roads and Maritime Services (2012) Pavement deflection measurement (falling weight deflectometer) T177, Roads and Maritime Services, North Sydney NSW

Roads and Maritime Services (2012) Determination of deflection and curvature by deflectograph T191, Roads and Maritime Services, North Sydney NSW

Roads and Maritime Services (2013) Proof rolling test T198, Roads and Maritime Services, North Sydney NSW

Roads and Maritime Services (2014) Deflection testing of road formation T199, Roads and Maritime Services, North Sydney NSW