

## Technical advice note, Pavement Deflections – an overview of measurement and interpretation

### Introduction

The National Pavement Technical Group (NPTG) has prepared this advisory note to discuss and outline the limitations of pavement deflection testing. The NPTG is a sector group of pavement specialists and industry representatives, including NZTA. The NPTG provides advice to NZTA and the wider industry in relation to research and development and subsequent technical direction.

The purpose of this Technical Advice Note (TAN) is to provide a background to pavement deflection testing, with guidance on:

- Why deflection is measured,
- Available deflection test methods,
- Interpretation and use of the measured deflection data,
- The limitations of deflection testing.

Deflection testing is normally done by either a Benkelman Beam to measure the maximum pavement deflection under a static load, or by Falling Weight Deflectometer (FWD) to measure the deflected shape of the pavement. Other devices such as lightweight deflectometers (LWD) and traffic speed deflectometers (TSD) or the multi speed deflectometer (MSD) are also available on a more limited basis.

Pavement design and construction involves the assessment and use of natural materials. Natural materials are variable and are not always uniform or consistent. Additives such as lime, cement and bitumen are sometimes added to these natural materials to enhance their performance.

In addition, our design process is mechanistic-empirical (M-E). In simple terms this means that the design model is based on historical pavements performance (a best fit line through the data has informed the design process).

The combination of pavement material variability and an M-E design approach means that outputs from the model need to be treated with care and engineering judgement, especially when comparing them to the properties of the constructed pavement.



Figure 1 A trailer mounted falling weight deflectometer (left) and a Benkelman Beam and truck set up (right)

### Why undertake deflection testing

Deflection testing gives us some insight into the condition of the pavement as a whole. Depending on the device used and the measurements recorded, the following information may be able to be *inferred* from the measurements:

- a) stiffness of the subgrade,
- b) the stiffness and condition of the upper pavements layers,
- c) the variability of the pavement through the site.

Deflection testing on an existing pavement, prior to a pavement or surfacing renewal, can provide insight into the condition of the pavement and existing subgrade, either in the raw form (deflection values) or via a predictive modeling tool to estimate the remaining life of the pavement.

During subgrade preparation and pavement layer construction, deflection testing can help the designer understand whether the design model deflection outputs are being realised during construction. If the measured deflections are greater than the calculated values, the designer needs to consider why – are the assumed material properties correct, is there an issue with the test process or is it construction related?

Deflection testing on the subgrade is beneficial as it allows the designer to review and adjust the pavement design if the measured subgrade properties do not meet the assumed properties. When undertaking deflection testing with impulse load devices such as an FWD it is worth bearing in mind the stress sensitive nature of subgrades. The drop weight used should be adjusted in relation to the nature of the soils being tested so as not to overstress the material causing failure. As an example, a reduced weight may be applied to stress softening material such as a silt or clay relative to the weight applied to a stress stiffening material such as a sand or gravel.

Deflection testing on the basecourse layer surface prior to placing an asphaltic concrete (AC) layer (either structural or thin surfacing) can provide an assurance that the pavement will provide a sufficiently stiff anvil to allow for compaction of the AC during construction and sufficient ongoing support to achieve the design life of the AC in service.

### Deflection uses in pavement modelling

Mechanistic pavement design uses analytical processes to calculate the pavement response (i.e. plastic/permanent strains) at critical locations in the pavement structure. These strains are used to predict the expected life of the pavement in terms of load repetitions. To calculate the strains in the pavement, the properties of the pavement layers (material type, stiffness and thickness) are required as inputs to the model. In addition to calculating the strains in the pavement, deflections (elastic/recoverable strains) are also calculated.

Variations in the layer thicknesses and material properties model inputs influence the model outputs. The designer needs to understand the limitations and sensitivity of the inputs as they interpret the results. An example of this is the conversion of CBR values to modulus (stiffness) for subgrades. Not all subgrade materials exhibit the commonly accepted CBR/modulus multiplier of 10. Multipliers ranging

from 5 to 20 have been published in previous pavement design guides, and even down to 2 for pumiceous and volcanic soils, from earlier research in NZ. Testing on the exposed surface of the subgrade during construction is the best time to confirm the actual subgrade stiffness.

By measuring deflection during construction of the pavement layers, the designer can compare the measured deflection response of the constructed pavement design models predicted deflections. As mentioned in the introduction, the simplicity of the design model and the natural variability of materials mean this comparison should be treated with care and engineering judgement.

### Deflection uses in pavement performance assessment

Deflection testing is also undertaken at a wider network level to help inform asset management decisions. Due to the variability of the pavement structure and maintenance histories across the network, in-depth or position specific findings should not be considered in the absence of other data.

Dependable pavement performance assessments using deflection data alone provide a lower level of accuracy than when they form part of a broader suite of information. When assessed in conjunction with known pavement layer thicknesses and material types, the results are more meaningful. This pavement data is not generally available at a network/route level. Incorporating other pavement condition measures such as roughness, rutting and cracking with the deflection data usually gives a better result for network level interpretation.

### Back calculation using deflection data

The transformation of deflection measurements to layer stiffnesses is referred to as back calculation. In this process the layer properties of the pavement model are iteratively adjusted until the difference between the measured and calculated surface deflections are within an acceptable range. There are a range of proprietary software programmes to complete this back calculation<sup>1</sup>.

Pavement analysis processes are based on linear elastic theory and the analysis models assume that layer stiffness decreases with depth. The presence of a stiffer underlying layer, such as a fully bound subbase, will create an inverted pavement structure. This can result in anomalous values.

In addition, for back calculation, the minimum modelled thickness for a pavement layer should be at least 25% of the diameter of the loaded area, i.e. a minimum of 75 mm for an FWD measurement (which uses a 300 mm diameter plate). Attempting to back calculate thinner layer moduli is not appropriate.

In addition to the traditional linear elastic static back calculation processes, there are also a number of non-linear and/or dynamic models available. Care and engineering judgement should be applied when using this type of higher level analysis to test or compare pavement designs that have been undertaken using the current M-E linear elastic design processes. Almost all back calculation software packages determine pavement layer stiffnesses on an isotropic basis 1V:1H, whereas Austroads assumes unbound

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<sup>1</sup> \*1 FHWA-HRT-16-009 "Using Falling Weight Deflectometer Data with Mechanistic-Empirical Design and Analysis, Volume I: Final Report", March 2017, provides examples of commonly used programs for back calculation  
<https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/16009/16009.pdf>

granular layers and subgrades to be cross-anisotropic 1V:2H. This aspect needs to be considered when undertaking back analysis.

For locations where the pavement layer thicknesses and properties are confidently known, performance outputs from the analysis of deflection measurements are considered to be more reliable.

### Limitations of the technology

As with any method there are accuracy limitations on the physical measurement of deflections and the analysis processes used to model pavements. This can include variations in the test methodology used, environmental issues affecting repeatability and material influences.

The current pavement design process in New Zealand uses a linear elastic model framework with static loads. Current deflection measurement techniques range from:-

- static (plate load tests),
- slow rolling (Benkelman Beam),
- impulse (falling weight deflectometer and LWD),
- fast rolling (traffic speed deflectometer (TSD), multi speed deflectometer (MSD)).

As computational power increases, the pavement analysis models have also advanced and can now account for the transient and dynamic loading effects. It is noted that these advanced models rely on material property assumptions that are difficult to measure. The performance predictions of these models often do not have a robust or proven links back to field performance.

Benkelman Beam testing is readily available, quick and economic. However, previous studies have shown a high degree of variability in the results between different operators and equipment when testing the same pavement. This variability does not discount or rule out the use of Benkelman Beam testing, but the potential variability in results means due care and judgement needs to be applied when setting construction targets and interpreting the results. Generally larger tolerances should be applied for Benkelman Beam values when compared with FWD values and results should be assessed holistically, rather than in isolation.

FWD, TSD and MSD testing is an automated testing and measuring process so the results tend to be more repeatable. However as outlined above, the loading and measuring effects (static, impulse, rolling) can influence the results. This is particularly relevant to asphalt material layers which are temperature dependent, so appropriate conversion algorithms need to be applied to layer temperatures recorded.

Care needs to be taken when comparing deflections between different measurement methods as the measurement type will influence the deflection. Either parallel testing, or established correlations, should be used to compare different test methods.

In situations where the pavement constructor has met the material and construction specification requirements for the pavement layers but the measured deflections are greater than the design deflections, there are a number of reasons that could contribute to the offset:-

- testing too soon after construction on a fresh pavement,
- elevated moisture levels in the pavement materials,

- degree of cure for cemented materials,
- high variability in the subgrade stiffness,
- incorrect assumptions for pavement layer properties,
- incorrect CBR/modulus relationship for soil type,
- the presence of deep seated weak layers such as peat soils.

The risk of not meeting deflection expectations can increase in marginal construction and weaker subgrade conditions. This is because subgrade performance changes exponentially when the subgrade CBR is 3.5% or less (<2 blows per 100mm when testing with a Scala Penetrometer)

The scale and risk profile of the project should inform the amount and type of deflection testing that is completed on the intermediate layers in the pavement. Intermediary testing should be considered when working with soft subgrades, heavy loads, and the need for stiffer base layers to accommodate AC surfacings.

Deflection measurements on the final pavement layer prior to surfacing will give an indication of the future performance of the pavement. Likewise, testing a fresh pavement may not give the expected deflection, however testing after a period of time following construction (usually within 1 year) usually lets a pavement settle down and deflections will often reduce.

## Recommendations on deflection uses in our industry

The various design guides (NZ, Austroads and Local Authority design standards) provide recommended pavement deflection limits based on the classification of the pavement. These values have been developed and refined over time with the experience of good and bad) pavement performance and provide a guide to appropriate pavement deflections.

If deflection measurements are to be used during pavement construction, then practitioners need to understand the limitations on the design models, material characterisation, measurement device and construction process and set/calculate targets accordingly. For example if the deflection is calculated via a Benkelman Beam axle in the M-E model but an FWD is used to check the constructed deflections, then an adjustment factor needs to be applied. These are provided in Austroads guidance documents.

Due to the influence of these aspects, deflection testing should not be used as a compliance/contractual instrument in isolation, rather they should form part of the toolbox that is used to assess the construction quality of the pavement rather than being the only tool. This does not negate the Constructor's requirement to use best practice and meet specified requirements.

Deflection testing during pavement construction is best done at:

1. Subgrade or Subgrade Improvement Layer (SIL) level to establish/confirm that the subgrade properties/stiffness are understood, and that the pavement design is appropriate for the actual subgrade conditions.
2. Prior to placing the first asphaltic concrete layer to confirm that the underlying pavement has sufficient stiffness to construct and support the asphaltic concrete layer(s).

Calculation of a design deflection should be done using the same assumptions/model setup that was used for the pavement design and the process/assumptions used for the calculations should be included in the design documentation.

Likewise, the selection of a method for analysing Non Destructive Test (NDT) data to determine layer moduli should be compatible with the analysis procedure that will eventually be used for designing the flexible pavement rehabilitation.