Material and Structural Interpretation of Dynamic Response Data

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ABSTRACT:
Load response data collected with the foundation layers to pavements using the light weight deflectometer have been plotted by frequency and by spacial location. The plots show that the light weight deflectometer is sensitive to aggregate grading and packing and a meaningful interpretation of the data can enable a prediction of the surface deflection pattern with a complete pavement, and can be used to certify foundation layers with a pavement. Using the dynamic surface modulus of granular material layers and soil foundation and the dynamic stiffness modulus of asphalt layers a 'long-life' deflection signature with a flexible pavement construction can be made.

KEY WORDS: LWD, FWD, Data Distribution, Data Interpretation, Performance

1. 1 INTRODUCTION

The structural integrity of a constructed roadway pavement is measured by dynamic load response; in the UK the measurement may be in a semi-continuous manner by a deflectograph, or in a series of discrete measurements by a Falling Weight Deflectometer (FWD). Both machines mobilise the whole pavement structure in terms of deflection through surface applied loading. Whereas the Deflectograph measures the maximum deflection of a pavement under the effective centre of the surface applied vertical wheel load, the FWD measures the surface deflection bowl. The profile of the surface deflection bowl provides information on the relative load distributing competence of the main material layers forming a construction: the upper bound aggregate layers, the lower granular layers and the soil foundation.

Knowledge of the structural competence of a roadway pavement with time is important to road managers, as it allows maintenance and intervention measures to be planned. Today with the construction of new sections of a roadway network or the reconstruction of sections of an existing roadway network, funding bodies as well as road managers require information on initial structural competence and an assessment of the structural life of a roadway: mangers require information to plan interventions, overseeing organisations require information on financial projections. As a result of a series of structural assessments in Scotland with new sections of the strategic network that suggested a shorter life than intended by the design, more detail on the structural competence of material layers during construction with new projects was requested. This resulted in additional performance measures being taken on material layers during construction than required commonly by a construction contract. The additional information related to the load response characteristics of the material layers forming the foundation platform, and the bound layers forming the pavement structure. This, along with the thickness values of construction layers, is input data to a forward prediction of the structural competence of the pavement, and provides a check on the structural competence defined from composite (whole pavement) load response data. The load response characteristics of the granular layers were defined using the German Dynamic Plate (GDP) and Light Weight Deflectometer (LWD); composite load response characteristics were measured using the FWD. Load response characteristics of the granular layers and composite construction were measured on Scottish contracts using machines developed by Carl Bro Pavement Consultants (formerly Phoenix): the Prima 2100 (FWD) and Prima 100 (LWD). With a number of Scottish contracts, pavement layer and whole pavement load response characteristics and data analysis were carried out by Pavement Technology Limited (PTL).

A similar approach has been adopted on the non-strategic roadway network, through the work of PTL with their private and public sector partners. The approach adopted has been to use the LWD as a tool to assess the structural competence of foundation platform layers with private and public sector pavements. The need with the non-strategic network has been driven by the introduction of recycled and secondary aggregates (RSA), which have little evidence of long term performance.

Data from contracts with the strategic network, non-strategic network and private sector pavements have been used in a pilot study carried out by PTL to interpret the competence of material layers and composite structures during and after construction.

2. DATA MEASUREMENT

The manner of operation of the tools used to record the load response characteristics of material layers and composite construction, the Falling Weight Deflectometer (FWD) and LWD. The FWD has been in wide use across the world for many years with a vast amount of papers published on its use on bound and unbound pavement layers. A more detailed description of the LWD can be found in the literature (Fleming et al. 2000; Kamiura et al. 2000; MacNeil and Steele 2002; Rogers et al. 2000; Thom and Fleming 2002; Van Gurp et al. 2000). The FWD assesses the load-response characteristics of composite or whole structures. The LWD is a more recent load-response characterisation tool. The tool assesses the state of compaction of a material layer, and defines the characteristic of dynamic surface modulus with a material layer. A LWD has several variations: German Dynamic Plate (GDP), also known as the Light Drop-Weight Tester or Zorn ZGF-01, TRL Foundation Tester (TFT), Prima 100 and Loadman and Handy type of FWD (HFWD). The devices follow the same operational principle as the FWD. A weight is dropped from a height onto a load plate and the applied load and resultant deflection of the material are measured. In the majority of devices the amount of load applied to a material layer and supporting structure can be varied by varying the drop height of the weight; the magnitude of the surface contact stress can be varied by changing the size of the loading plate. The applied load is known or is measured using a calibrated load cell. The surface deflection of the material layer and support structure is measured using either an accelerometer or geophone. A geophone measures the vertical velocity with a single integration to obtain the surface deflection, whereas a double integration is applied to the acceleration signal from an accelerometer. The devices convert load and deflection into an equivalent dynamic surface modulus.

With a LWD the stress bowl generated within a material layer is a function of the loading plate diameter and the magnitude of the load applied to the loading plate. With a small drop height and a smaller loading plate the smaller is the generated stress bowl beneath the plate and in a material layer. In such circumstances the deflection generated by an applied surface stress relates to the material forming the layer directly under the loading plate. The material forming the layer has little or no confinement as a result of any overlaying layer or structure. The deflection will thus be relatively high and the dynamic surface modulus low. With a greater applied surface stress caused by a higher load drop height the stress bowl is larger, generating stress deeper within the layer or within the support structure; material deeper within a layer or within a support structure has greater confinement. With granular material this effect results in a higher dynamic surface modulus as a result of a lower generated deflection. Although the applied material layer surface stress can be made to match that within a full construction, the deflection generated at the surface of the layer will be higher than within a full depth construction and the surface modulus lower. A correction is required to any measured dynamic surface modulus to relate the load response characteristic to full depth pavement construction.

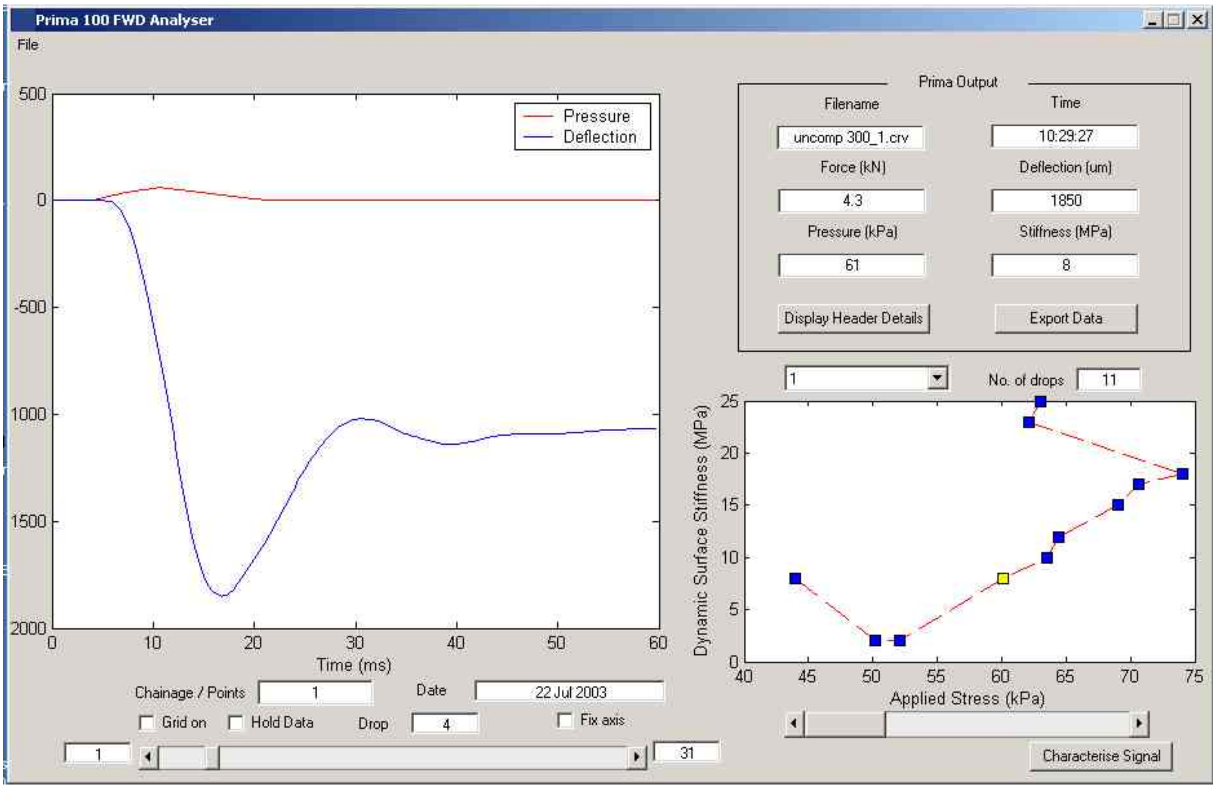
Figure 1 shows alternative versions of the Prima 100. At PTL an alternative screen display with the Prima 100 LWD has been developed to provide the operator with information on the load pulse deflection response (Figure 2). Such data provides the operator and analyst with additional information on the condition of a material layer and support structure.


(a) (b)

Figure 1: The Prima 100 (a) Laptop version (b) Wireless PDA version

3. LOAD RESPONSE DATA FROM THE STRATEGIC ROADWAY NETWORK

With the strategic network in Scotland the competence of material layers and composite structures has been gathered as additional but non-contractual data with contracts over the last three years. Only one specific contract is reported here. The load response characteristics of all layers were measured along with the whole construction. Table 1 is a summary of the test frequency.



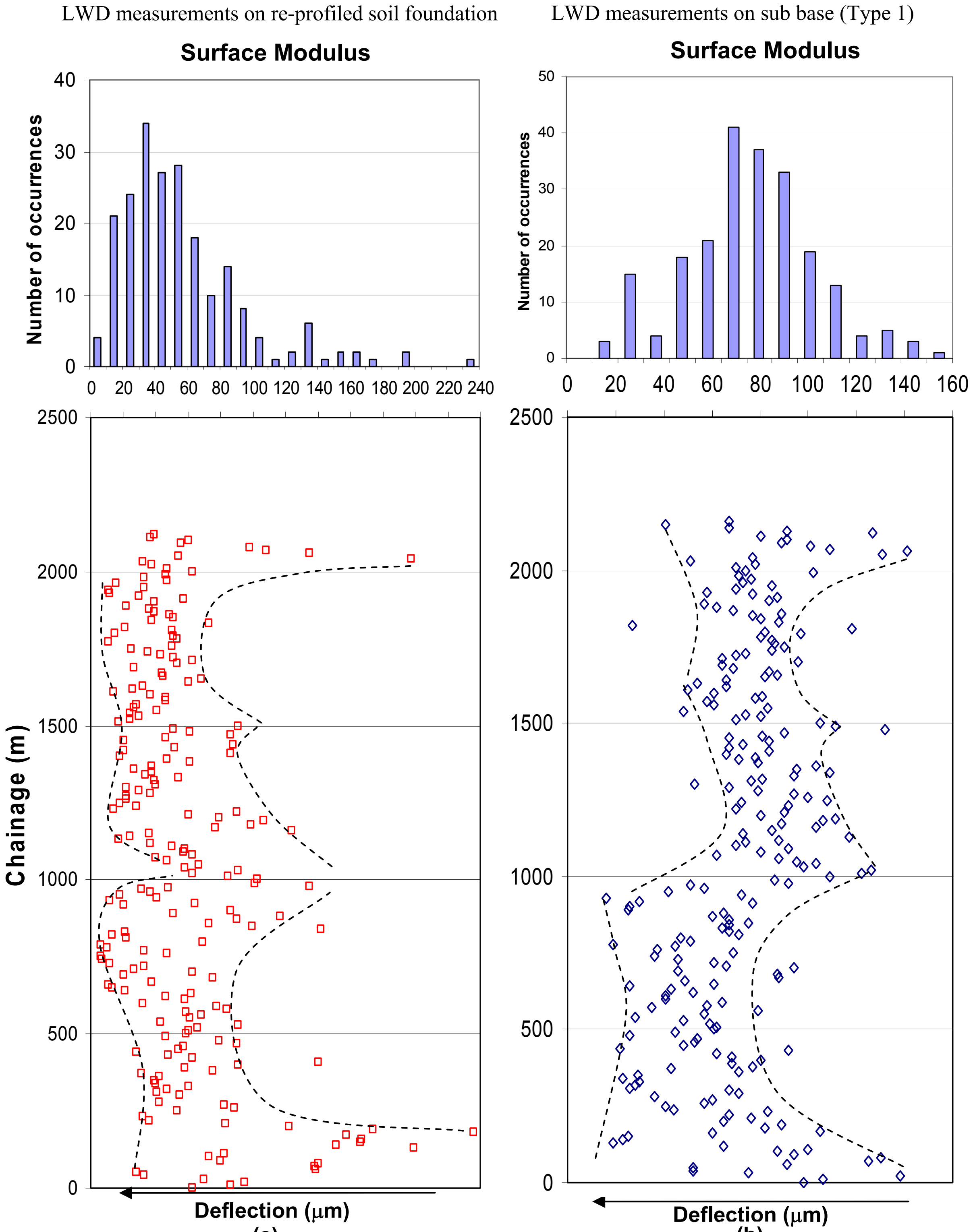
Filename: uncomp 300_1.crv
Time: 10:29:27
Force (kN): 4.3
Deflection (um): 1850
Pressure (kPa): 61
Stiffness (MPa): 8
No. of drops: 11
Chainage / Points: 1
Date: 22 Jul 2003
Drop: 4

Figure 2: LWD signal showing the deflection signal response of an under compacted material

Table 1: Test frequency used with strategy network roadway contracts

	Frequency of test points		
Material	Prima 100	GDP	FWD
Subgrade	25m	100m	-
Capping	10m	50m	-
Sub-base	10m	50m	-
Base and binder	-	-	20m

Plots of dynamic surface modulus with the re-profiled soil foundation and sub-base are shown in Figures 3a and 3b. The plots are shown in a manner developed to interpret the data; two contiguous plots of dynamic surface modulus are shown: a spacial distribution plot and a frequency distribution plot. Although machine suppliers provide data on the range of dynamic surface modulus to be expected with material layers they provide no information on structural interpretation. The plots show an interesting pattern. Firstly, the pattern shows, or infers, ‘subgrade or soil foundation reflection’: a similar spacial pattern of range of dynamic surface modulus is suggested with the two foundation platform layers. This is what is expected as the effective energy imparted to a material layer is a function of the weight of the roller and the bearing capacity of the support structure. A variation in the bearing capacity of the support structure may be expected to be reflected in an overlying layer. With the patternation events have happened at the beginning of the works and at chainage 1000, 1500 and 2000 that have created local areas of higher dynamic surface modulus. Secondly, with the sub-base there is a distinct change in range of dynamic surface modulus values between changes 0000 and 1000, and greater than chainage 1000. This was the result of the compacted sub-base layer being removed between chainage 1000 and 2000 and new material laid and compacted. The partially compacted sub-base was detected and corrected through the application of the LWD; this was vindication for the client in requiring such tools be used during construction: a performance approach was being taken to construction rather than the traditional method approach.



(a)

(b)

Figure 3: Frequency and spatial distribution plot of LWD data on (a) re-profiled soil foundation (b) sub base layer

With the asphalt layers forming the pavement with the particular roadway cores were drilled and dynamic stiffness modulus values from Indirect Tensile Stiffness Moduli (ITSM) tests were defined for each layer. FWD load response characteristics of the structure were measured at the top of the base course, binder course and the running surface of the pavement. Using the range of temperature and load time corrected dynamic stiffness modulus values with the asphalt layers and the confinement corrected range of values of dynamic surface modulus with the foundation platform layers, a forward analysis was carried out on the pavement. Figure 4 shows the range of predicted surface deflections occurring directly under the loading plate of the FWD, expected immediately after construction. The data shows what is expected: the subgrade bearing capacity has the most significant effect on surface deflection of all the pavement layers. The effect of the variation in subgrade bearing capacity on generated surface deflection is greater than the variation in dynamic stiffness modulus of the bound layers, assuming the bound layers are fully bonded and acting compositely.

From Figure 4, with a higher bearing capacity soil foundation and with this particular pavement construction, the range of predicted surface deflections is in the range 100microns to 200 microns for all conditions of the pavement layers and foundation platform layers. Interestingly, the effect of loss of interface bond within the base layer is marginal in terms of measured pavement surface deflection. The increased surface deflection directly under the load remains significantly less than that caused by reduced subgrade bearing capacity. However, measured surface deflection and residual structural life of the pavement are distinctly different. In Figure 4 the values on the histograms are the predicted structural lives for the particular conditions of interface bond within the base layer and range of layer stiffness. To confirm a ‘long structural life’ construction, as required by the client, the ‘deflection signature’ of the pavement should be less than 150 microns. A value of surface deflection between 150 microns and 350 microns could mean a long life pavement, but knowledge of bond interface conditions within the base is needed. Between a centre point deflection of 150 microns and 350 microns the shape of the surface deflection bowl may be able to distinguish between a weak foundation and long structural life and partial interface bond within the base and a significantly reduced structural life.

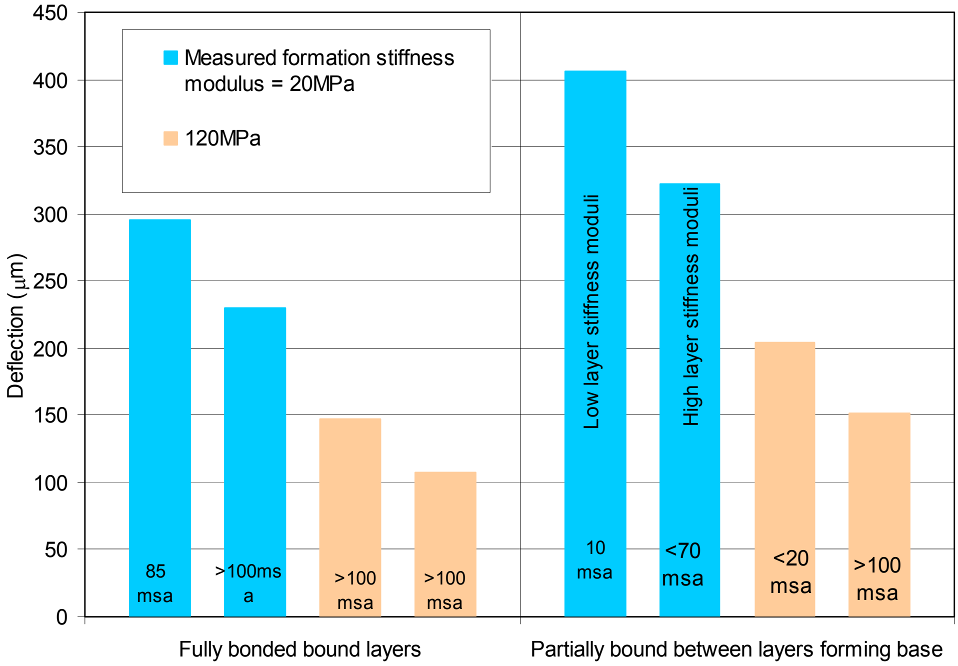


Figure 4: Shows the range of predicted deflection values and pavement life on two different foundation stiffnesses.

Deflection plots made by the FWD, corrected for temperature, are shown in Figure 5 for the same chainage length. The surface centre point deflection profile (upper profile) has a similar patternation to that of the re-profiled soil foundation with low deflection values at the beginning of the contract and at chainage 1000, 1500 and 2000. The values of centre point deflection are less than 200mm in general, suggesting that the pavement is likely to have an indefinite life; the random single high FWD measured deflections are likely to be machine effects. The combined asphalt layer deflection profile (lower profile) reflects appears to reflect the sub-base profile measured by the LWD, specifically in relation to the increased deflection between the beginning of the contract to chainage 1000.

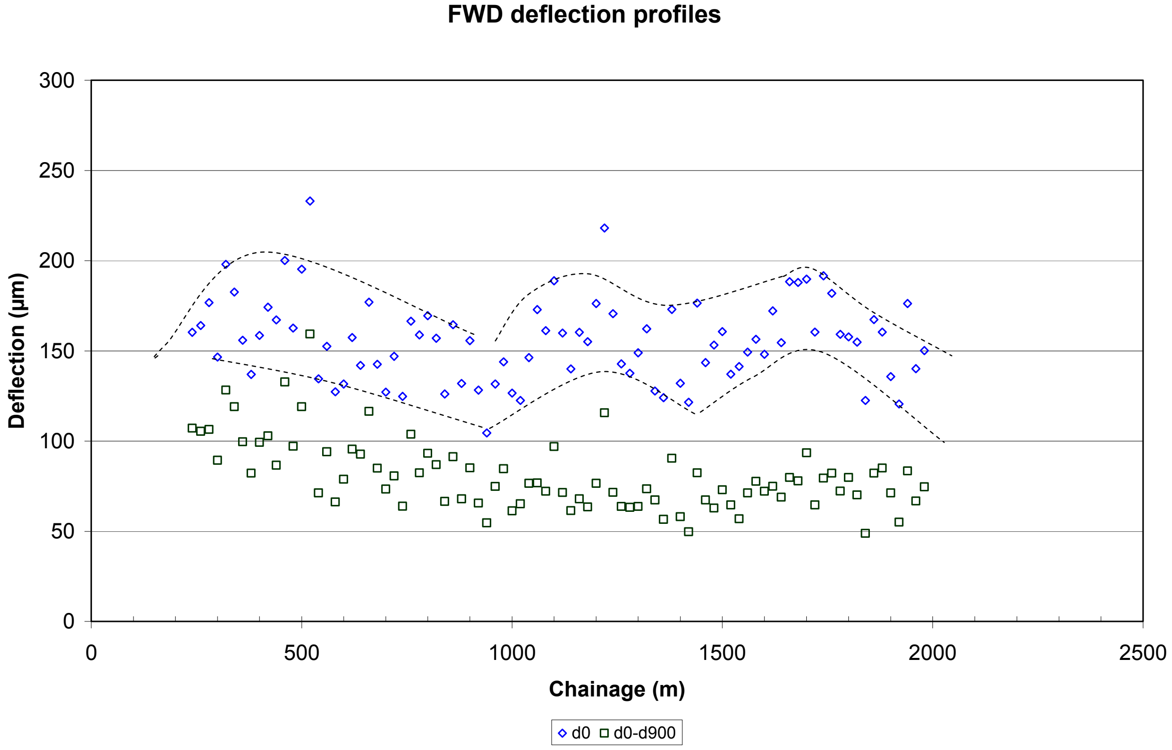


Figure 5: FWD deflection profiles (d0 – overall pavement performance; d0-d900 – condition of bound layers)

The conclusions of the work with the strategic network is that dynamic response data gathered during construction can be used to predict centre point surface deflection values measured using the FWD, and LWD data on the subgrade can be used to predict centre point surface deflection value profiles measured using the FWD, the added value of using construction data is that information is available about the dynamic response characteristics of all layers of a construction and layer thickness values. FWD back-analysis calculation has to make assumptions for those values; in addition actual fatigue characteristics can be used in structural life prediction, rather than normalised data as with the back-analysis calculation with FWD.

Currently where high surface deflections are recorded early in the life of a pavement two issues are raised by contractors and design engineers: lack of stabilisation of the moisture in the soil foundation through the sub-soil drainage system, and maturing interface bond within the base layers. The forward analysis with load response data from all pavement layers with a particular strategic network contract suggests that whereas soil foundation bearing capacity does have a distinguishing effect on pavement surface deflection, base interface layer bond does not necessarily have a distinguishing effect in terms of pavement surface deflection. The data from the particular strategic network pavement described indicates that an ideal deflection signature is less than 200 microns, a deflection signature between 200 microns and 250 microns may create a long structural life pavement but the cause of the higher pavement surface deflection requires to be defined, possibly through the shape of the deflection bowl.

4. LOAD RESPONSE DATA FROM THE NON-STRATEGIC ROADWAY NETWORK

Currently it is unusual to carry out the same approach to pavement design with the non-strategic network as is used with the strategic network. Assessment of residual structural life is carried out, but not commonly. However, the need of the client and network manager to expect 'adequate' structural life from a construction is just as critical. A similar approach has been taken by PTL with particular non-strategic network and private sector projects as was described with the strategic network.

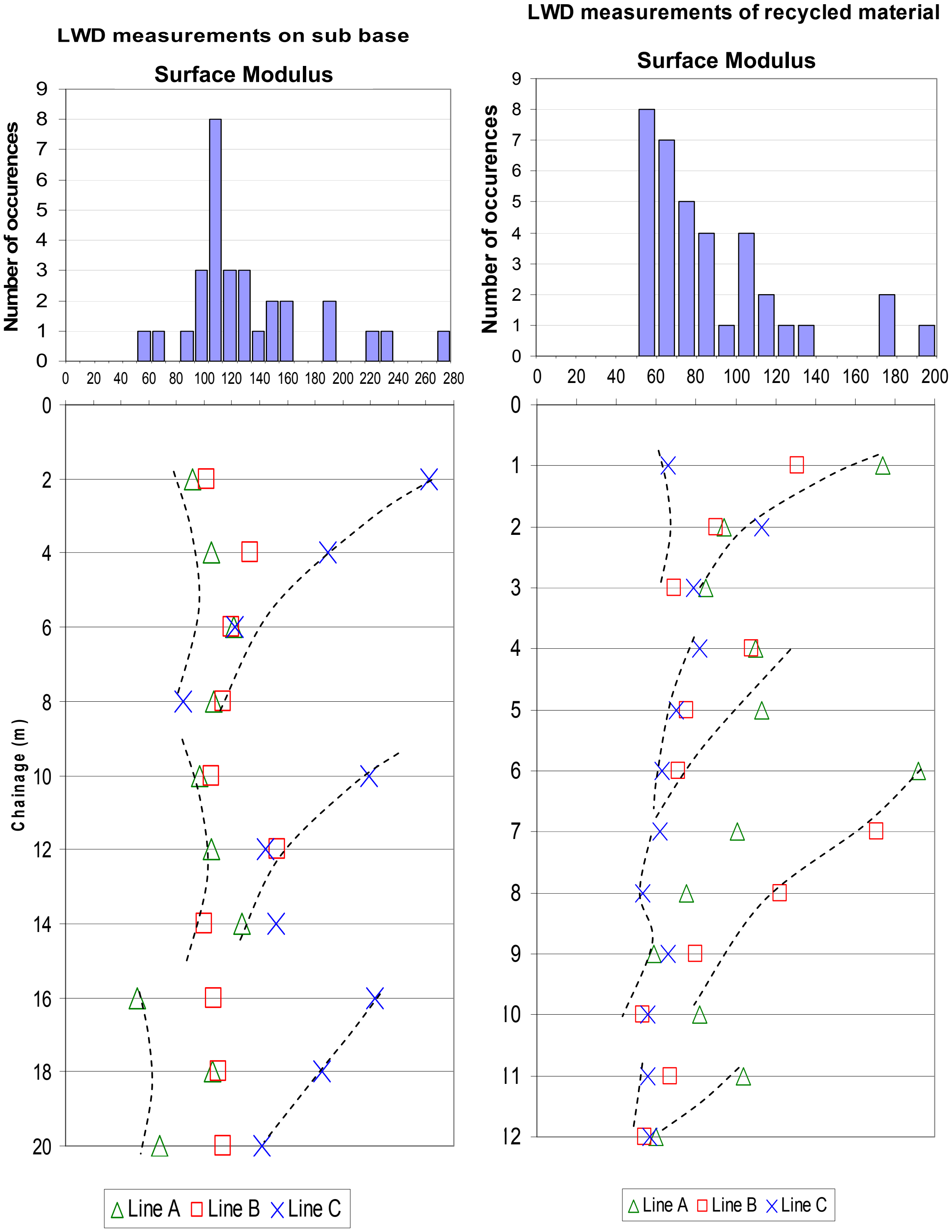
Two projects built pavement structures on highly stiff foundations: one foundation was concrete, the second foundation was rock. In both cases a sub-base was applied directly to the foundation. One sub-base was formed of Type 1 granular material, the other was a modified crusher-run material that was not compliant with the Type 1 grading envelope. Figure 6a shows the spacial and frequency plot with Type 1 aggregate compacted onto a concrete foundation; Figure 6b shows a similar plot with the modified crusher-run aggregate onto a rock foundation. Then two plots show distinctive patternations in the spacial plots that are not reflected in the frequency plots, just as with the strategic network data.

With Figure 6a, the plots reflect the manner in which the aggregate was placed and spread on the foundation, and subsequently compacted. The common range of dynamic surface modulus values is tight and at the upper end of the Type 1 sub-base material used on the strategic network over areas of stiff foundation. The tight spread of dynamic stiffness modulus values relate to areas where material piles were formed before being spread to create a level surface prior to compaction. The higher values of dynamic surface modulus values reflect segregation in the material layer caused by the manner of spreading the material. The pavement construction over this foundation platform was a stone tile construction to form a pedestrian area. No FWD data was defined with this construction.

With 6b, the plots also reflect the manner in which the aggregate was placed and spread on the foundation, and subsequently compacted. Here the material was a modified crusher-run material; Pulverised Fuel Ash was added to the aggregate and the aggregate laid at optimum moisture content. The material was finer than a Type 1 aggregate by the addition of ash. Fours 'loads' of material were dumped onto the rock surface and spread by machine bucket. Again there is a variation in range of dynamic surface modulus values. The common value range for dynamic surface modulus, and the range spread, is less than that for a Type 1 aggregate; this reflects the finer grading of the material. The surface to this foundation platform was asphalt to form a car park. No FWD data was defined with this construction.

5. CONCLUSIONS

The work reported suggests that the LWD is an effective tool to measure the dynamic surface modulus of granular material. The tool appears to be sensitive to the grading and packing of granular material, as shown with the data from the non-strategic network. With the strategic network there is evidence that indicates that the use of the LWD can enable prediction of the patternation of 'centre-point' surface deflection under a wheel load or plate of the FWD, and the values of dynamic surface modulus generated, along with stiffness values for bound layers, can effectively predict pavement surface centre point FWD deflections.



(a) (b)

Figure 6: Frequency and spatial distribution plot of LWD data gathered on sub base situated on (a) Concrete (b) Rock

The forward prediction of the load response characteristics of layers forming a new construction can identify a 'long-life' deflection signature for the construction, and can define deflection values that may have an issue with structural life. Two characteristics of a pavement control surface deflection and structural life: subgrade bearing capacity and interface bond within layers forming the principal structural layer.

Foundation platform layers can be 'certified' using both the output signal from the LWD and from plots of dynamic surface modulus values; the sensitivity of the LWD gives it the potential for accepting granular material used to form foundation platform layers created from recycled and secondary aggregates.

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