PERFORMANCE TESTING OF UNBOUND MATERIALS WITHIN THE PAVEMENT FOUNDATION

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ABSTRACT: Pavement design requires knowledge of the performance of the foundation layers. The specific condition at a given site can be considered in the design; such as the use of locally available material, recycled or secondary aggregate in the pavement foundation, provided the specified end-product performance requirements are achieved.

Performance testing is required in order to ensure that the design assumptions for the material properties are met during construction. Both the capping and sub-base layers need to attain adequate strength and stiffness. Therefore there is a need to undertake complimentary compliance testing that would include target values based on the behaviour of the materials.

This paper describes the research into the development of performance testing for foundation layers based on case studies performed by Scott Wilson Pavement Engineering (SWPE). The performance testing was carried out by Falling Weight Deflectometer (FWD), German Dynamic Plate (GDP) and Prima 100. The results using these test methods were compared and correlated.

The results indicated that the relationships between FWD, GDP and Prima were material type and thickness dependent. The Prima usually gave broadly similar results to the FWD, but was significantly more variable from point to point. The GDP almost always gave a lower stiffness than the other devices, but to varying degrees.

1 INTRODUCTION

The road foundation layers, which consist of the capping (where necessary) and sub-base layers that overly the natural soil subgrade, perform several functions both during construction and when the road is in service. In particular they act as load-spreading layers to reduce to acceptable levels the stresses transmitted to the subgrade, (often as temporary haul roads during construction), and as construction bases on which the overlying pavement layers can be adequately laid and compacted. The critical loading conditions usually occur during construction where the materials are directly trafficked, and hence where the applied stresses are greatest. The materials that are used for the capping and sub-base layers need to have both adequate stiffness and strength to perform satisfactorily.

The usual current UK specification for road foundations (MCHW Vol.1 2004) is based on a recipe approach, whereby selected materials are laid and compacted with specified plant in a specified manner to achieve a minimum level of performance. The pavement foundation designs are based primarily on the use of the California Bearing Ratio (CBR) to characterise the subgrade, capping and sub-base materials. Here CBR is used as a measure of both material strength and stiffness. Although CBR has been correlated with pavement performance in many countries over many years and provides a trusted empirical indicator of material behaviour, the use of CBR as a performance parameter is widely acknowledged as being not wholly satisfactory (Brown 1996). Furthermore, the need for a fundamental engineering property (such as stiffness) to describe the unbound material has become important for use in analytical/mechanistic design methods.

Advances in the in-situ testing of pavement foundation materials now allow the performance parameter of stiffness (and, more indirectly, strength and resistance to permanent deformation) to be measured on a routine basis during construction. This in turn enables a performance-based specification for road foundation layers to be introduced, hence facilitating the use of secondary aggregates, marginal materials and stabilised ground.

The stiffness modulus of a pavement foundation is a measure of the quality of support which is provided to the overlaying asphalt or concrete layers. Recent developments of in-situ testing devices have now made it possible to obtain a direct measure of the stiffness modulus during construction. Use of such devices for compliance testing is becoming a real possibility and ultimately may be expected to supersede the use of the California Bearing Ratio (CBR) test, considered by many countries as being not wholly satisfactory.

Considerable research has been undertaken over the past few years to develop in-situ testing devices that quickly measure the stiffness of the subgrade and the pavement layers during construction (Fleming at al. 2000). These devices measure a composite stiffness under a transient load pulse, which is applied to the ground by dropping a weight onto a bearing plate via a rubber buffer. The deflection of the ground is measured and combined with the applied load, which is either measured or is assumed to be constant (by means of a constant drop height), to calculate the stiffness using conventional Boussinesq static analysis. Such devices include Dynamic Plate Tests (e.g. Falling Weight Deflectometer (FWD), German Dynamic Plate (GDP) and Prima 100).

This paper describes an investigation in to the differences between in-situ testing devices (FWD, GDP and Prima 100) at live construction sites and comparison of results for stiffness measured using these apparatus.

2 EXPERIMENTAL DETAILS

2.1 *TRIAL SITES*

The testing results of five trial sites established by Scott Wilson Pavement Engineering (SWPE) have been used for this experiment (Thom 2003). The sites were selected in order to cover as wide a range as possible of foundation materials as well as site and contractual conditions as outlined below:

- A2-M2 Cobham to Junction 4 Widening. Trials performed on capping comprising stabilised clay with flints as well as crushed concrete
- Realignment of Taxiway Alpha, Jersey Airport. Full contractual implementation of the proposed Performance Specification, resulting in significant savings to the Client
- Widening of Church Way, Doncaster. Trial to demonstrate the applicability of the Performance Specification within an urban environment where construction proceeded in a piecemeal fashion
- A27 Polegate Bypass. Trial performed on a lime and cement stabilised Weald Clay subbase
- A43 Towcester to M40 Dualling. Trial to assess the site-won Oolitic limestone capping

For all these projects, Dynamic plate testing (FWD, Prima and GDP) was conducted. Tests were conducted on the surface of the subgrade and capping following all surface preparation work prior to construction of the subsequent pavement layer.

The tests were first performed with the FWD, since the towing vehicle is fitted with a distance-measuring device, and the equipment can provide several repeat measurements with different drop heights (applied loading) to investigate load related effects. Following each FWD test, the location of the load plate was circled with spray paint and given a station reference number (this referencing is evident in Figure1). This allowed the ‘portable’ GDP and Prima equipment tests to be performed at exactly the same locations, in order to assess whether a correlation with the FWD equipment could be obtained. The FWD is well established testing device, which is widely used as a bench mark.

Figure 1. Test at sub-formation level comprises FWD, Prima and GDP testing at the same location as FWD

2.2 *TEST EQUIPMENT*

The Dynatest manufactured 8001 Falling Weight Deflectometer (FWD) – Stripped of all additional weights the FWD provides a minimum falling weight of around 50kg which, when raised to a drop height of around 70mm delivers a measured (by a load cell) pulse load of 100kPa via two round-topped rubber buffers. In addition, the static assembly mass (providing a degree of static pre-load through the load plate) is around 50kg. The 150mm radius load platen was fitted (as standard) with a rubber mat in an attempt to provide an improved contact with the test surface. Deflection is measured by a geophone (which measures velocity, which is then integrated to obtain vertical displacement i.e. deflection) located above a 10mm diameter tip at the centre of the load plate.

The Carl Bro manufactured Prima has a falling weight of 10kg which, when raised to a drop height of around 900mm delivers a measured (by a load cell) pulse load of 100kPa via four rounded conical buffers. In addition, the static assembly mass is around 16kg. The 150mm radius load platen is not fitted (as standard) with a rubber mat. In the modified form used, deflection is measured by a geophone located above a 30mm diameter plunger at the centre of the load plate.

The German manufactured German Dynamic Plate (GDP) has a falling weight of 10kg which, when raised to a drop height of around 750mm delivers an assumed (by prior calibration) pulse load of 100kPa via a spring. In addition, the static assembly mass is around 20kg. The 150mm radius load platen is not fitted (as standard) with a rubber mat. Deflection is measured by an accelerometer (which requires double integration to obtain the deflection) built into the 300mm diameter load plate.

3 RESULTS AND DISCUSSION

Dynamic Plate Tests were carried out using three pieces of equipment, the Falling Weight Dflectometer, Prima and German Dynamic Plate. The surface modulus/stiffness results (E_{vd}), based on vertical deflection, were calculated using the following equation:-

$$E_{vd} = PRF \times (1-\nu^2) \times r \times p / d \quad (1)$$

where E_{vd} = Surface Modulus (MN/m2 or MPa)
PRF = Plate Rigidity Factor (= 2.0 for Prima, and $\pi/2$ for FWD & GDP)
n = Poisson's Ratio (set at = 0.35 for all three pieces of equipment)
r = Load Plate Radius (= 150mm)
p = Contact Pressure (normalised to 0.1MN/m2 or 0.1MPa)
d = Vertical Deflection (mm).

A summary of correlations between the FWD stiffnesses and both the Prima and GDP (equipment under trial) stiffnesses for two sites between A43 Towcester and M40 Dualling is presented in Table 1.

Table 1. Summary of Stiffness Correlations

Test Location	Factor to be applied to FWD stiffness to equate to PRIMA/GDP stiffness							
	Site 1: Tusmore				Site 2: Baynards Green			
	PRIMA		GDP		PRIMA		GDP	
	Run 1	Run 2	Run 1	Run 2	Run 3	Run 4	Run 3	Run 4
Top of Sub-base	-	-	-	-	1.16	-	0.92	-
Top of Capping (Formation)	1.11	1.14	0.44	0.42	0.80	1.02	0.62	0.63
Top of Subgrade (Sub-Formation)	0.89	0.87	0.36	0.35	0.67	0.69	0.48	0.43

It is evident from Table 1 that the factors to be applied to the FWD stiffnesses, to equate to the PRIMA/GDP stiffnesses, are consistent between the adjacent Runs but differ between the two sites and the two pieces of equipment.

Testing results of the different devices on five construction sites and on a number of subgrade, capping and sub-base layers were compared. The dynamic plate test plays a central role in this experiment and in general it has been found to be both user-friendly and contract-friendly. However, the issue of the different results obtained from the three different devices used in this project (FWD, Prima and GDP) is a serious one, and needs further discussion.

Firstly, in several instances the results obtained showed that:-

- the Prima was subject to a high degree of scatter on some sites
- the GDP measured much lower than the other two devices on most sites

The FWD was confirmed as the most "robust" of the three on which to base the Specification limit, and it was decided to plot the data from the other two devices against that from the FWD. [Note: Procedures already exist for annual calibration of FWD if the equipment is to be used on Highways Agency projects]. The data is shown in Figure 2 for all locations where both the FWD and at least one other device were used. Also shown in Figure 2 are two suggested correlation lines, one for the Prima and the other for the GDP:-

$$E\,(Prima) = E(FWD) \times 1.273 \quad (2)$$

$$E\,(GDP) = E(FWD) / [1+E(FWD)/150] \quad (3)$$

Next, the degree of inherent scatter expected was considered. This had been evaluated at most of the sites, based on either repeat testing or on several tests performed within a small area. Typical standard deviations ranged from 10% to 30% of the mean, with relatively high values on coarse capping and higher values for the Prima than the other devices. Figure 3 has been generated as a random set of data for comparison with Figure 2. The same mean correlations as found for Figure 2 have been assumed to apply, but a random scatter has been applied to a given set of 'real' stiffnesses, with standard deviations of 20% of the mean for the FWD and the GDP, but 30% for the Prima, approximately matching the experience to date.

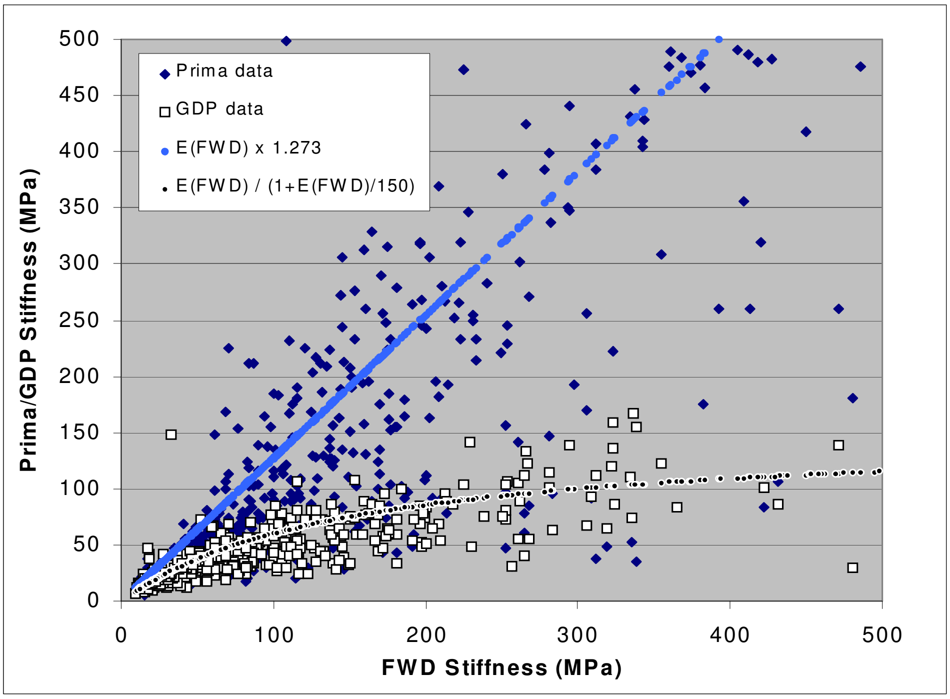

Figure 2. Comparison of Actual Stiffnesses from Dynamic Plate Tests

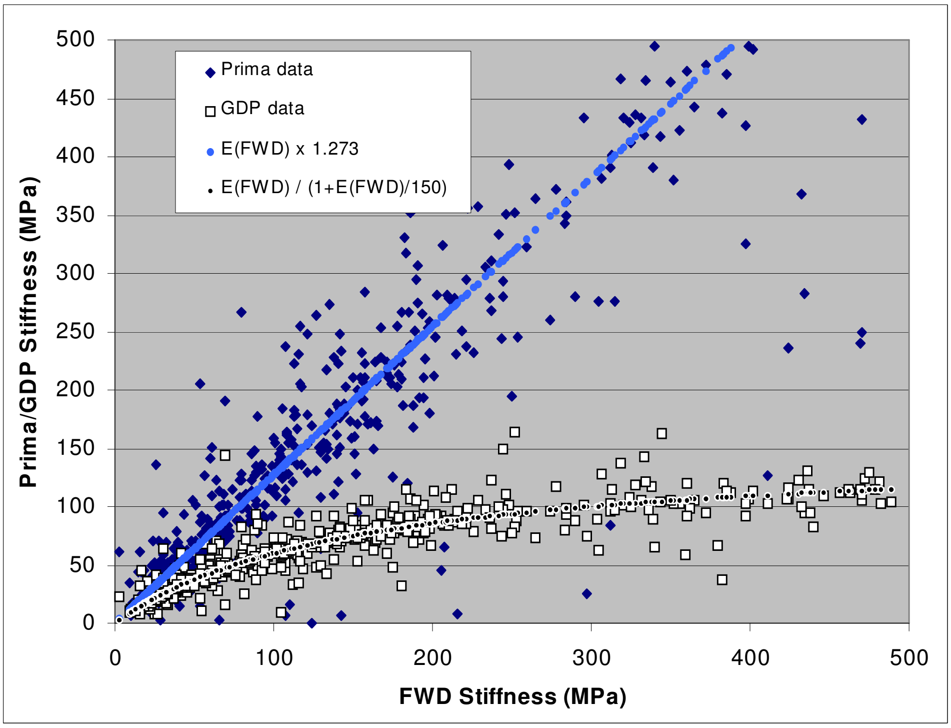

Figure 3. Comparison of Generated Stiffnesses based on Measured Scatter

Clearly, Figures 2 and 3 are visually comparable. The conclusion is that inherent variability may be responsible for virtually all the lack of correlation observed.

The other issue is the actual correlation applying. The factor between the FWD and the Prima, 1.273, is simply due to a different assumption regarding plate stiffness; the Prima analysis assumes a rigid plate (plate rigidity factor of 2), whereas the FWD analysis assumes a flexible plate (plate rigidity factor of π/2). The correlation between deflections is approximately 1:1.

The correlation between the FWD (or the Prima) and the GDP is much less satisfactory. This is undoubtedly due to the GDP measuring only acceleration, with an assumed conversion to stiffness. Because of the flatness of the correlation at higher stiffness, the GDP is clearly not suited to surfaces with stiffness greater than about 100MPa. The formula suggested in Figures 2 and 3 is considered appropriate at FWD measured stiffness values up to 100MPa (GDP measurements up to 60MPa), since it actually lies slightly higher than the mean of the data. If a straight line relationship is assumed, then a ratio of 1.5 is approximately correct up to 100MPa, but use of the curve shown is considered to be both simple enough and also 'safer'.

With the slightly safer correlation given for the GDP, and the Prima analysis corrected to the flexible platen assumption, either device is considered suitable for use in the performance testing (the GDP only on the basis of an agreed correlation for each particular construction), although FWD testing would be recommended wherever possible in order to obtain more data with which to improve the proposed correlations.

4 CONCLUSIONS

- The relationships between FWD, GDP and Prima were found to be material type and thickness dependent. The FWD is still regarded as being the most appropriate device for setting the standard, not only because the loading is most representative of real traffic, but it can also be used for assessment of all pavement layers as construction proceeds.
- The Prima usually gave broadly similar results to the FWD, but was significantly more variable from point to point.
- The GDP almost always gave a lower stiffness than the other devices, but to varying degrees.
- The GDP in particular was found to be very user-friendly.
- The proposed simple statistical treatment of the data was found to work satisfactorily
- Either the FWD or the Prima (current version, modified to measure ground deflection through a hole in the plate) can be used for measurement of stiffness, as long as the same plate rigidity factor is assumed (π/2 for a flexible plate). If the Prima default setting (rigid plate, rigidity factor of 2) is assumed, then a correction factor must be applied, such that E(FWD) = E(Prima) / 1.273
- The GDP can be used for measurement of stiffness up to 60MPa (approximately 100MPa with the FWD); as long as a correlation has been obtained between the devices for each specific construction type.

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