A COMPARATIVE EVALUATION OF THE STRUCTURAL CAPACITY OF CRACKED AND UNCRACKED FLEXIBLE PAVEMENTS USING MECHANISTIC EMPIRICAL METHODS BASED ON DEFLECTION MEASUREMENTS BY THE FALLING WEIGHT DEFLECTOMETRE (FWD) AND A TRAFFIC SPEED DEFLECTOMETRE DEVICE (TSDD)

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ABSTRACT

The FWD has been used for the past three decades in South Africa to emulate a loaded wheel while taking measurement of vertical deflection of the road surface at various offsets from the load. The measured deflection bowls have been used in conjunction with the pavement profile to determine the layer stiffness moduli and ultimately the structural capacity. The FWD test measures the surface deflection via a static vertical impact load. This is contradictory to reality where wheel loads are imposed in a dynamic rolling motion while the pavement exhibits visco-elastic behaviour due to vertical and horizontal stresses. The TSDD is a dynamic loading device that uses Doppler laser technology to calculate deflections using measured horizontal travelling velocity and vertical surface displacement velocity. It could therefore be said that this loading mechanism more accurately simulates actual traffic loading compared to the FWD.

The study involves two 100m sections of road P21-1 in Kwa-Zulu Natal, one section was recently rehabilitated and is in a good condition while the other adjacent section is in a state of advanced fatigue. The FWD and TSDD measurements were performed in the outer wheel path at one metre intervals and the continuous TSDD deflection measurements were performed at various traveling speeds. This study aims to investigate the difference between the deflection measurements obtained from these two devices when the structural capacity of the pavement is calculated using mechanistic empirical evaluation methods. Also included in this paper is a comparison of the structural capacities of a 36.5 km section of Provincial Road P21, based on FWD and TSDD measurements.

1. INTRODUCTION

Pavement response as a result of an impact load has long been studied to better estimate the integrity and structural condition of the road. Various devices were developed over time and some of these are used in South Africa. The evolution of these devices occurred due to the need for higher accuracy, less time consuming and more cost efficient results.

The first device was the Benkelman Beam, developed in 1952, which measures pavement deflection when subjected to a static rolling wheel load. The Benkelman Beam method is slow and labour intensive and is therefore more suitable for project level investigations. The inefficiency of the Benkelman Beam on network level assessments resulted in the development of the Deflectograph which allows for measurements to be taken at a speed of approximately 2.5 km/h. This allows for high frequency measurements that are suitable for network level but measurement efficiency of the Deflectograph is still poor at 2.5 km/h.

The FWD originated in France in the ‘60s and has since become the most widely used deflection measurement device in the world, including South Africa where the FWD has been used since the ‘90s for project and network level assessments. The device attempts to simulate a moving wheel load by dropping a short impulse load onto the pavement. The pavement response to the load creates a deflection bowl, as shown in Figure 1, which is measured by geophones that are positioned at various distances from the load centre.

The FWD is currently considered to be the most suitable device for deflection surveys. The stationary testing at each test point do however raise traffic accommodation and safety concerns. The stop start nature of the FWD test means that deflections are performed at a low frequency.

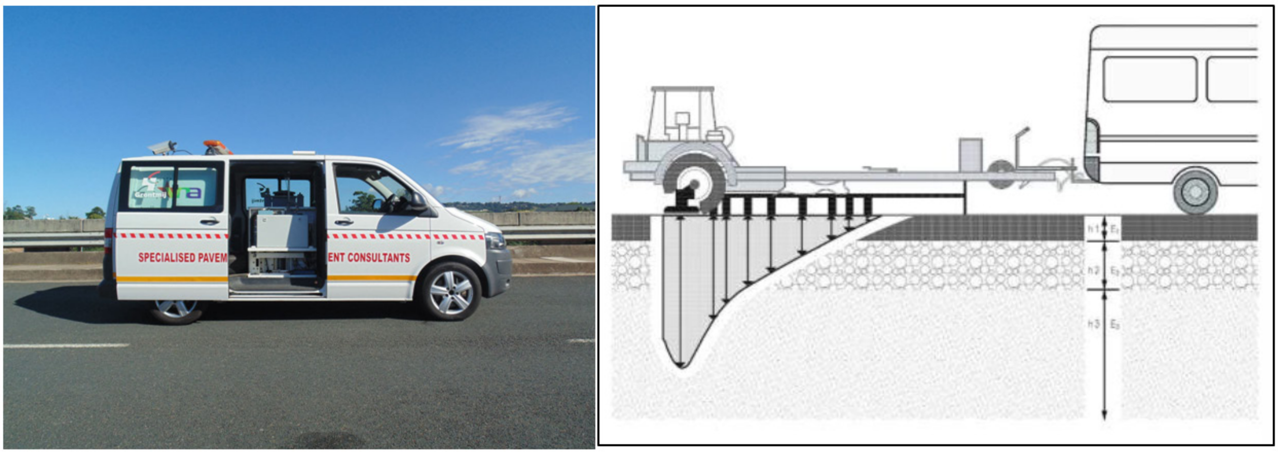

Figure 1: Falling Weight Deflectometer (FGSV, 2004)

The latest development in deflection measurement is the Traffic Speed Deflectometer Device (TSDD). The TSDD is a vast improvement on the Deflectometer and operates at traffic speeds of up to 80 km/h. The iPAVe version of the TSDD that was used in this study is shown in Figure 2. It uses a patented Doppler laser technology beam, also shown in Figure 2, to measure the vertical displacement velocity at various offsets from the loaded wheel. The area under curve method by Muller and Roberts (2013) is used to convert deflection slopes to a deflection bowl which represents the pavement’s response to the wheel load of the TSDD.

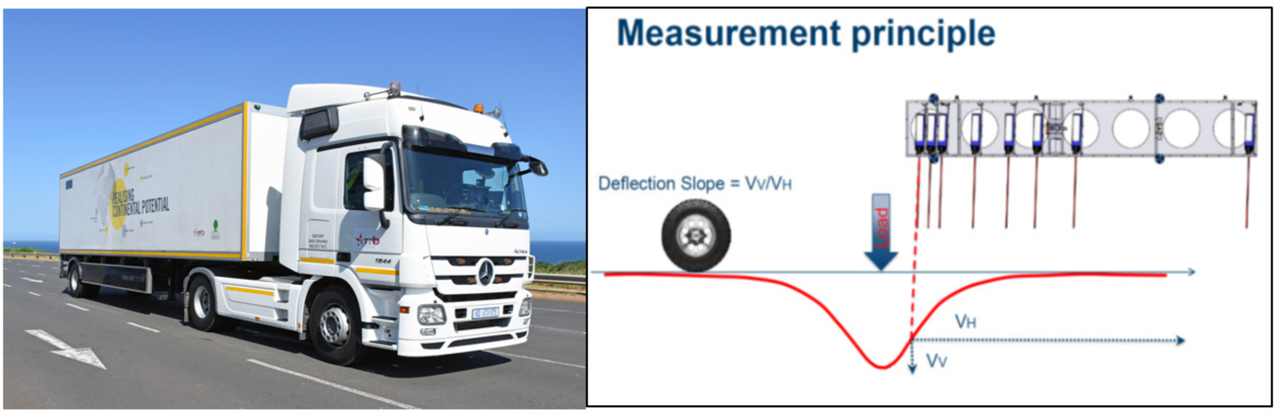

Figure 2: iPAVe Traffic Speed Deflectometer Device (left) and Doppler laser beam (right)

The particular iPAVe device, used in this study, features a 7 laser Doppler beam in front of the left rear wheel. The iPAVe includes integrated laser crack detection, digital imaging and a class 1 laser profilometer in addition to the traffic speed deflectometer for structural measurements. This allows for a comprehensive pavement assessment that simultaneously provides integrated functional and structural condition data. Compared to the FWD, the TSDD has a much higher deflection measurement frequency (every 25 mm), a lower test duration per test and allows for improved safety to the road user and operator.

2. STUDY AREA AND FIELD TESTING

The study area is located on Provincial Road P21, also referred to as R603, which is located south of the N3 between Pietermaritzburg and Durban. The FWD and iPAVe testing was performed on P21-1 from km 5.527 to km 5.627 and on P21-2 from km 8.260 to 8.360. P21-1 was recently rehabilitated and is in sound condition while the P21-2 section is in a visually distressed condition. The test sections are each 100m in length.

The aim of this study is to investigate the differences between the deflections measured by the FWD and the iPAVe and to establish the effect that this difference has on the calculation of layer stiffness moduli and structural capacity using a mechanistic empirical approach. The findings could validate the possibility of using iPAVe deflection measurements in the absence of FWD measurements. In order to meet this objective, the field testing required FWD and iPAVe testing as well as an intrusive pavement materials investigation.

2.1 FWD Measurements

Deflection testing was performed over one day in May 2019 and one day in August 2019 using two FWD devices. Duplicate testing will be referred to throughout this paper as FWD 1, FWD 2, FWD 3 etc. Deflection testing were performed in the outside wheel path at one metre intervals. Duplicate testing was performed on the same day and shortly after each other to reduce the effect of temperature variation. Morning and afternoon test results are differentiated to isolate the effect of temperature. The trial sections were set out by measuring the road with a measuring wheel and marking each one metre test location. The actual testing times were recorded and is shown in Table 1.

Table 1: Actual FWD testing times

	07 MAY 2019				08 AUGUST 2019			
	P21-1		P21-2		P21-1		P21-2	
DEVICE	Start	Finish	Start	Finish	Start	Finish	Start	Finish
SWECO	08:13	09:26	10:03	11:32	07:39	09:32	10:09	11:22
SWECO	13:58	14:57	12:34	13:29	12:20	13:40	14:26	15:38
ERAY	-	-	08:55	10:14	-	-	-	-
ERAY	12:14	13:14	13:37	14:38	-	-	-	-

The deflection measurements on the two 100m sections were conducted on exactly the same test location during the duplicate tests. This resulted in a total of 1100 FWD tests or

11 duplicate deflection measurements at each one metre interval performed on both P21-1 and P21-2. The FWD devices were calibrated and the geophones adjusted to South African standards as prescribed by the TMH 13.

2.2 iPAVe Measurements

iPAVe deflection testing was performed four times on P21-1 and three times on P21-2 immediately after and on the same alignment as the FWD testing locations. The deflection measurements were performed at speeds of 40 km/h, 60 km/h and 80km/h on each section and will be referred to as iPAVe 40, iPAVe 60 and iPAVe 80. Reflective cones were positioned at the start and end of the 100m sections to automatically trigger the iPAVe to record at these locations while traveling at the targeted speed. The iPAVe collects raw data at approximately 1000 Hz, or 25 mm, depending on traveling speed (Flintch et al., 2012). Each one metre deflection measurement was referenced to the corresponding FWD location using GPS coordinates.

Continuous deflection devices (CDD) such as the iPAVe, can contain high “noise” levels at low measurement intervals of up to one metre in length compared to static devices (Samer et al, 2013). To reduce these noise levels, measurements are typically averaged and reported over 10 m sections (Fintsch et al., 2012). For the sake of comparative purposes, this study uses iPAVe data over one metre intervals. Therefore, some degree of measurement noise can still be expected from the iPAVe deflection measurements during this study. A more practical approach to analyse iPAVe and FWD measurements using 50m intervals as a means of reducing this distortion is discussed later in this paper.

Evident benefits of using CDD technology compared to FWD are:

- Increased safety during deflection measurements due to the high speed travelled by the vehicle.
- High frequency of measurements (every 25 mm) to increase completeness of data, identify isolated weak pavement sections and other factors such as construction anomalies, sinkholes and changes in pavement type.
- High speed data collection to allow large networks of roads to be assessed in significantly shorter timeframe.
- Measuring pavement deflection using a rolling wheel load better simulates actual traffic loading as opposed to a static falling weight.

2.3 Materials Investigation

A representative pavement profile with known layer thicknesses is required for the two test sections to determine the layer stiffness moduli. These layer moduli are derived from the layer thickness and deflection basin at each location. Inspection pits were excavated on P21-2 and construction as-built records for P21-1 were confirmed by cores being drilled to accurately determine the upper pavement profile. The results of the pavement profiles for P21-1 and P21-2 are summarized in Table 2.

The pavement structures defined in Table 2 were used in the mechanistic empirical analysis of P21-1 and P21-2.

Table 2: Representative pavement structures used for P21-1 and P21-2

Pavement Structure for P21-1				
Layer	**Reference**	**Thickness (mm)**	**COLTO Class**	**Material Description**
1	Surface	40	AC	14 mm Continuously graded asphalt
	Base	80	BC	28 mm Bitumen treated base
2	Subbase	300	C4	Cement stabilized crushed sandstone
3	Selected	150	G6	Shale and mudstone
	Subgrade	-		Gravel and clay silt
Pavement Structure for P21-2				
Layer	**Reference**	**Thickness (mm)**	**COLTO Class**	**Material Description**
1	Surface	140	AC	2 layers of unknown mixture asphalt
2	Base	230	G5	Crushed sandstone, previously cemented
3	Subbase	200	G6	Shale and mudstone
4	Selected	300	G7	Highly weathered Mudstone
	Subgrade	-		Silty Clay

2.4 Limitations of Study

The intention of the study is to explore the possibility of using TSD deflection measurements for pavement structure evaluations in absence of FWD deflection measurements. There are certain limitations to the study due to the practical nature of the investigation and evaluation.

The use of handheld and built-in equipment thermometers to record air and surface temperature instead of in-depth pavement sensors means that this study is limited to only report on the effect of surface temperature and not differential pavement layer temperature. The raw deflection measurements, only normalised for load variability, were used for comparative purposes during this study and temperature correction was not considered for either the FWD and TSDD measurements.

Seasonal variability was not investigated although duplicate tests were performed during different times of the year to allow for this to be investigated in a future study.

3. ANALYSIS METHODOLOGY

Three different aspects of the pavement were studied to better quantify the possible difference in measured deflection between the FWD and iPAVe. These aspects are the deflection bowls, layer stiffness moduli and pavement structural capacity.

Firstly, the deflection bowl is analysed as this provides a raw and true reflection of the pavement's response to the load imposed thereon. Differences in the deflection bowls should identify a difference in response to the loading mechanism of the FWD and iPAVe. The deflection bowl represents the structural condition of the pavement at a specific location and is the point of departure for estimating pavement layer stiffness moduli and bearing capacity.

The estimated layer stiffness moduli, derived from each of the deflection bowls and pavement profiles, are used as input for the mechanistic empirical calculations and are an important aspect in defining the pavement behavioural state. The stiffness moduli of the pavement at a specific location are estimated using a back-calculation process whereby the stiffness modulus for each layer are adjusted iteratively to match the measured deflection bowl and the calculated deflection bowl.

The structural capacity is mainly dependent on the layer stiffness, traffic loading and material properties. The remaining life estimation is used to quantify the residual value of the pavement. Road Authorities budgeting and expenditure often make investment decisions based on this pavement capacity indicator. Therefore, it is important for this evaluation to be as accurate as possible in reflecting the actual pavement structural condition and bearing capacity.

3.1 Deflection Bowls

The deflection bowl of the FWD is comprised of the physical measured deflection at each geophone. These geophones are located at 0, 200, 300, 400, 600, 750, 900, 1200, 1500 and 1750 mm from the load centre and represent the magnitude of displacement caused by the FWD load.

The iPAVe measures the horizontal traveling velocity and the vertical deflection velocity of the pavement surface in response to the iPAVe wheel load. The surface deflection velocity is measured at each Doppler laser located at 100, 200, 300, 600, 900, 1500 and 3500 mm from the central position in between the dual wheels. The vertical pavement deflection velocity is divided by the horizontal velocity to derive the deflection slope or tangent at each laser. The combination of deflection slopes at each laser forms the deflection bowl as shown on the bottom right of Figure 3. The slope of the deflection is thus a derivative of the pavement displacement (Ferne et al., 2009). This allows indices such as maximum deflection (D_0), base layer index (BLI), middle layer index (MLI) and lower layer index (LLI) to be derived from the deflections.

The main difference between the iPAVe and FWD is the loading mechanism of a traffic speed rolling wheel load and a static falling load respectively. Because of the dynamic loading, iPAVe measured deflections can be influenced by surface irregularities such as surface distress and roughness (Flintsch et al., 2013). It is well known that the effect of traveling speed of the iPAVe during testing causes variability in deflection measurements (Mshali & Steyn, 2020). It can be expected that the iPAVe deflection bowls may be influenced by such factors in this study.

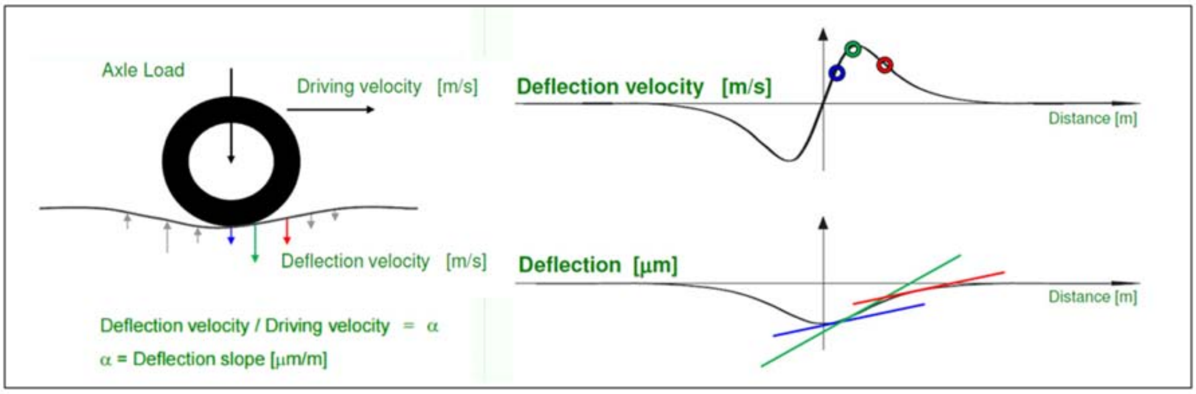

Figure 3: Deflection measurement principle of the iPAVe (Rasmussen et al., 2008)

The deflection bowls from the various duplicate iPAVe and FWD testing were compared at each one metre interval to obtain a better visual perspective of the differences between the two devices.

3.2 Pavement Layer Stiffness

The deflection bowl represents the pavement's ability to distribute the load imposed thereon. The shape of the bowl and magnitude of deflection provides insight into the stiffness of the entire pavement. A combination of the pavement profile and measured deflection bowl at a specific location is used to derive stiffness moduli for each layer.

This is done using a "back-calculation" process whereby stiffness values are assigned to each pavement layer and iteratively changed to match the measured and calculated deflection bowl. Each one metre deflection measurement in this study was used to back calculate the layer stiffness moduli. Rubicon Toolbox, a software package developed in South Africa for the use with FWD deflections, was used in this study.

3.3 Structural Capacity

The ultimate aim of this study is to compare the structural capacity or remaining number of load repetitions of pavements with different structural conditions using the iPAVe and FWD.

The method used in this study to estimate structural capacity is the Mechanistic Empirical Design Method that has been used in South Africa since the '90s. The method is based on historical input from various research contributions since the '80s (Theyse et al, 1995). The mechanistic empirical analysis method is based on Layered Elastic Theory (LET) for a layered, isotropic, homogeneous and non-linear pavement system. The method identifies the critical layer in the pavement when cumulative loading is applied which is then expressed in million equivalent standard axles (MESA).

Identical input parameters were assigned for the FWD and iPAVe mechanistic empirical analysis to ensure comparative results. The results of deflection bowls for each one metre location using the FWD and iPAVe was used in combination with the pavement structures illustrated in Table 2 to determine layer stiffness moduli. The pavement thickness, stiffness modulus (unique for each deflection test) and cumulative traffic loading, was used to estimate the bearing capacity of the pavement.

4. DISCUSSION OF RESULTS

4.1 Deflection Bowls

Duplicate deflection bowl measurements for the iPAVe and FWD are compared at each 20m location and represented in Figure 4 and Figure 5 for P21-1 and P21-2 respectively. The green lines represent the duplicate FWD deflection measurements and the orange represents the iPAVe deflection bowls. The difference in loading mechanism of the two devices may have an effect on the magnitude of the deflection measurements and shape of the deflection bowl.

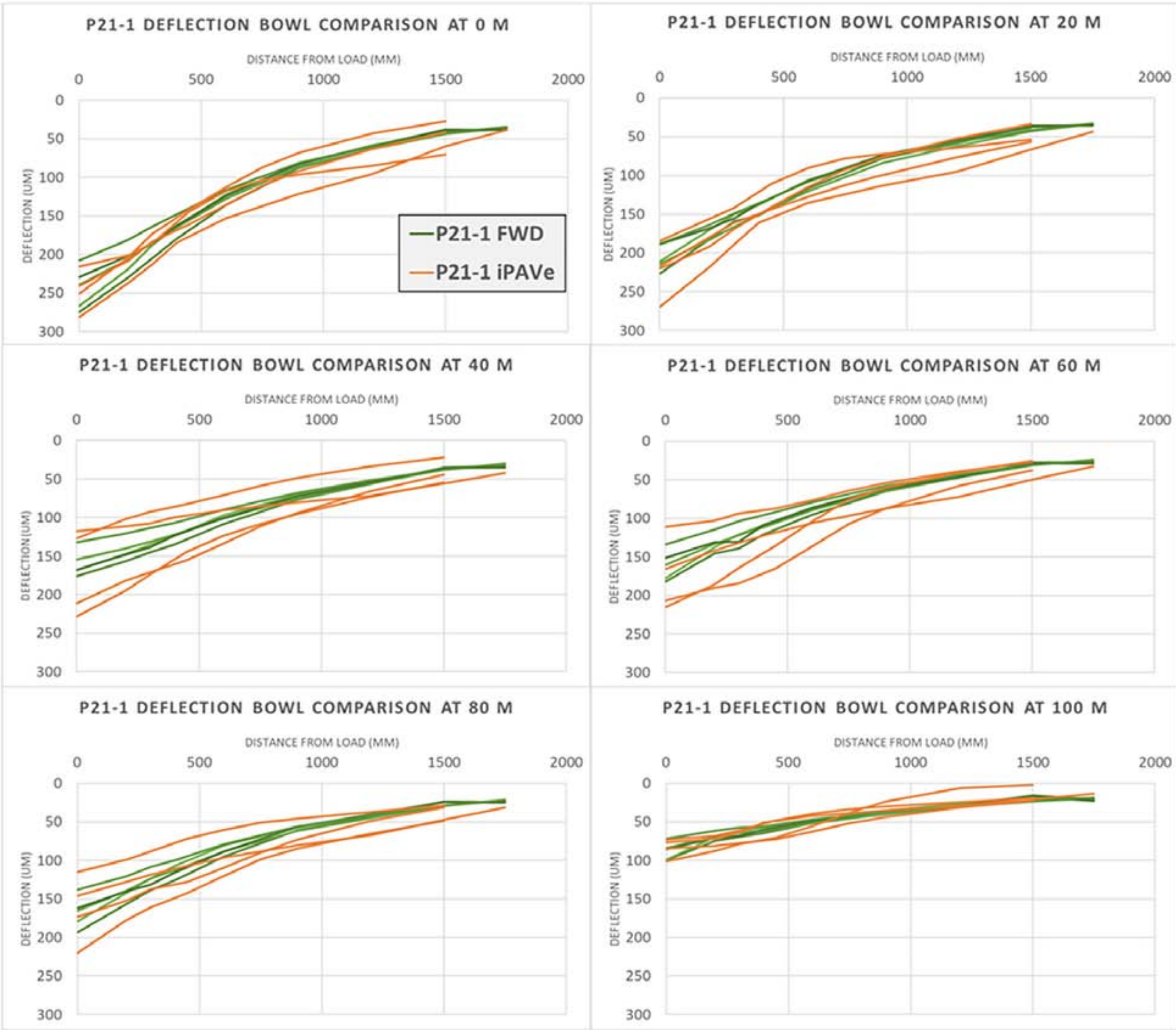

Figure 4: Actual FWD and iPAVe deflection bowls for P21-1 at each 20m location

The variance of the iPAVe bowls is greater than that of the FWD with a greater difference between the duplicate test results. The high variance in iPAVe deflection bowls, compared to one another, may be due to the difference in traveling speed during each duplicate testing (Mshali & Steyn, 2020). In general, the shape of the iPAVe deflection bowls are similar to those of the FWD and targets the same deflection range. Although there are similar measured deflection bowls for the iPAVe and FWD, a clear difference is noted between the deflection bowls of the two devices.

The deflection bowls for P21-2 are represented in Figure 5 and discussed thereafter.

The repeatability of each separate FWD and iPAVe test run is good and the variability of iPAVe compared to the FWD is lower than that P21-1 in Figure 4. The measured iPAVe deflections on P21-2 are consistently and marginally lower than the FWD from 0m to 60m, thereafter the deflection bowls become more similar.

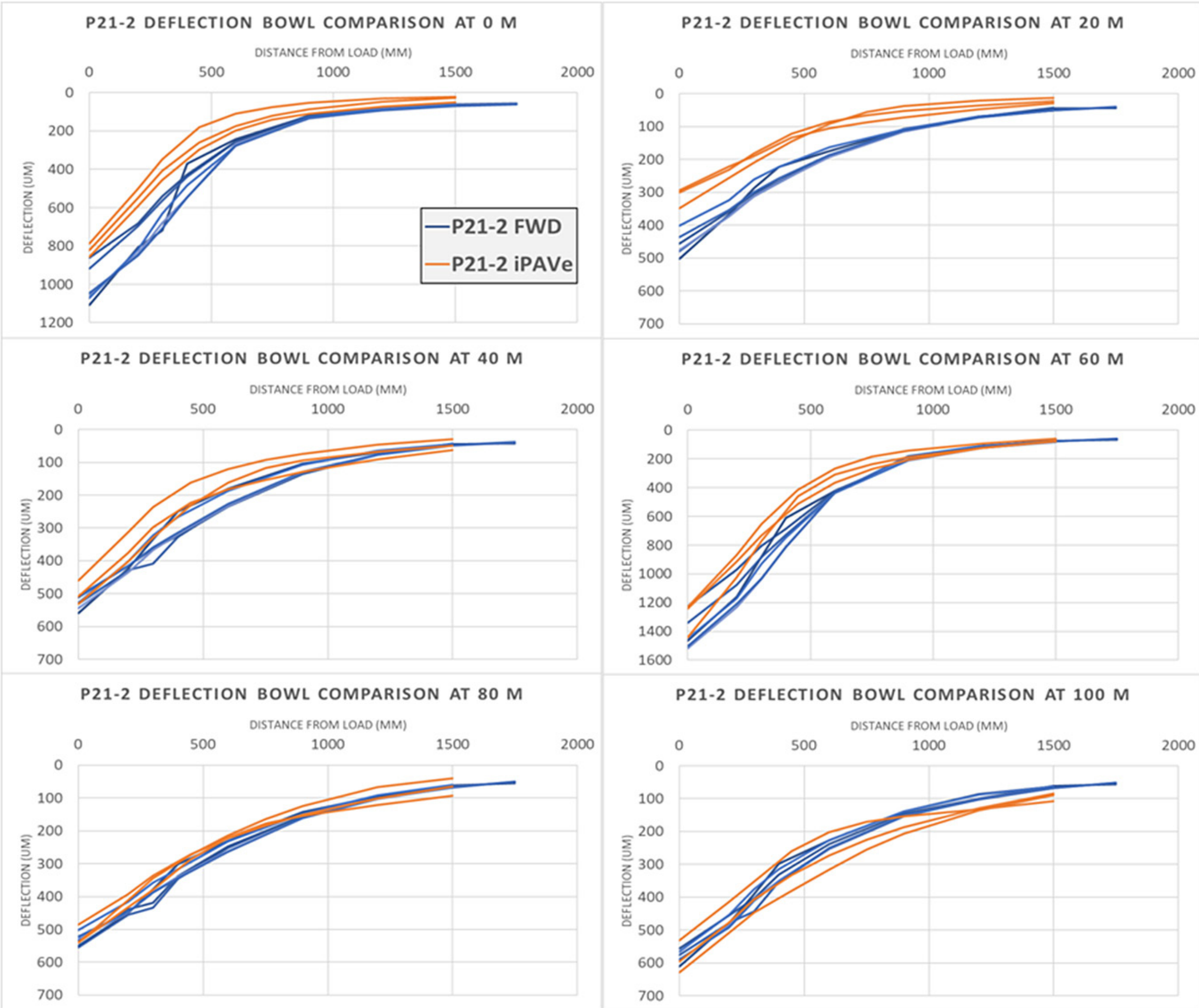

Figure 5: Actual FWD and iPAVe deflection bowls for P21-2 at each 20m location

The actual deflection bowls selected every 20 metres only represents a sample of the 100 deflection bowls compare over the 100m section. In order to represent each of the individual deflection measurements for the two 100m test sections, the median deflection bowls for P21-1 and P21-2 are plotted in Figure 6. The median deflection bowl for all FWD and iPAVe test results was used in a regression analysis to investigate the correlation of the deflection measurements of the two devices. The results are shown in Figure 7.

Figure 6: Median deflection bowls for P21-1 (left) and P21-2 (right)

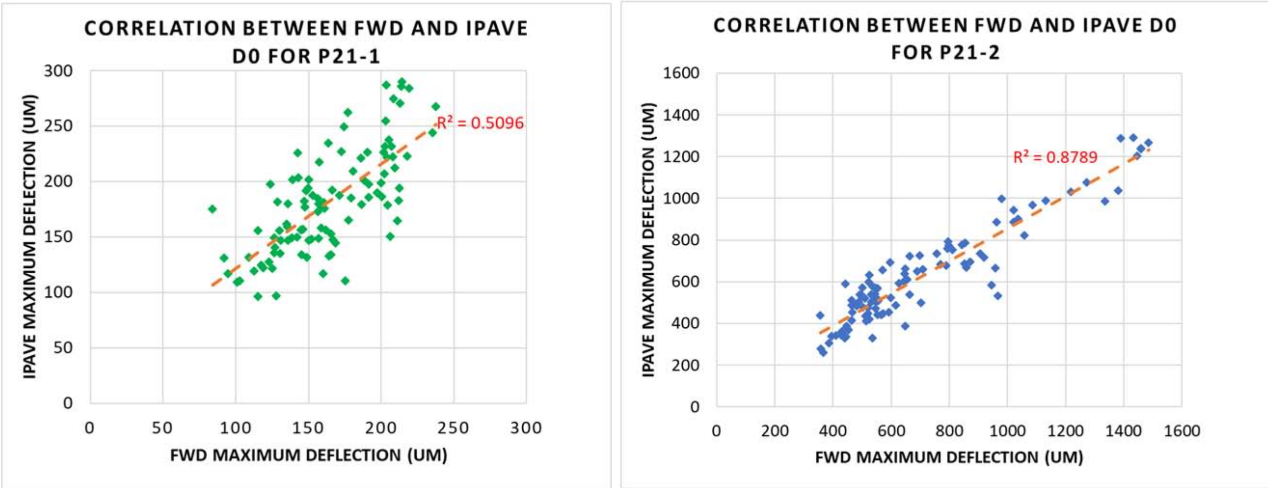

Figure 7: Regression analysis of D_0 measured by FWD and iPAVe for P21-1 (left) and P21-2 (right)

In conclusion, Figure 6 shows that there is some variability in the deflection bowls measured by the iPAVe and FWD devices. The deflection bowls of the duplicate iPAVe and FWD testing target the same range but with some variability. A R^2 value of 0.51 indicates a moderate correlation between the FWD and iPAVe measurements for P21-1. A good correlation is seen between the two devices for P21-2 with a R^2 value of 0.88.

The sensitivity of low deflection measurements is evident in the correlation results for P21-1. In addition, a difference in deflection magnitude can be expected due to the different iPAVe traveling speeds and the different nature of the two tests. The effect of this difference will be investigated in detail during the evaluation of layer stiffness and pavement capacity.

4.2 Benchmark Indices

A deflection bowl consists of curvature zones that can be isolated to investigate deflection indices (Horak, 1987). The deflection indices consist of the base, middle and lower layers and methods have been developed by which the contribution of deflection by each of these zones can be identified (Maree & Jooste, 1999). These parameters are maximum deflection (D_0), Base Layer Index (BLI), Middle Layer Index (MLI) and Lower Layer Index (LLI). The median deflection indices of each test run over the 100m sections of P21-1 and P21-2 are illustrated in Figure 8 and Figure 9 respectively and rated according to South African Pavements Engineering Manual (SAPEM) chapter 10 Table 44.

Based on the above analysis, it is clear that P21-1 is in a sound structural condition and P21-2 is in a severely distressed condition. The difference in deflection bowl indices between the FWD and iPAVe is insignificant as it has very little effect on the condition rating.

A scatter graph of the D_0 for each individual one metre location is presented in Figure 10. This allows for a better visual interpretation of the difference between the maximum deflection for the iPAVe and FWD on distressed and sound pavements. The graph includes the structural condition rating as per SAPEM chapter 10 Table 44.

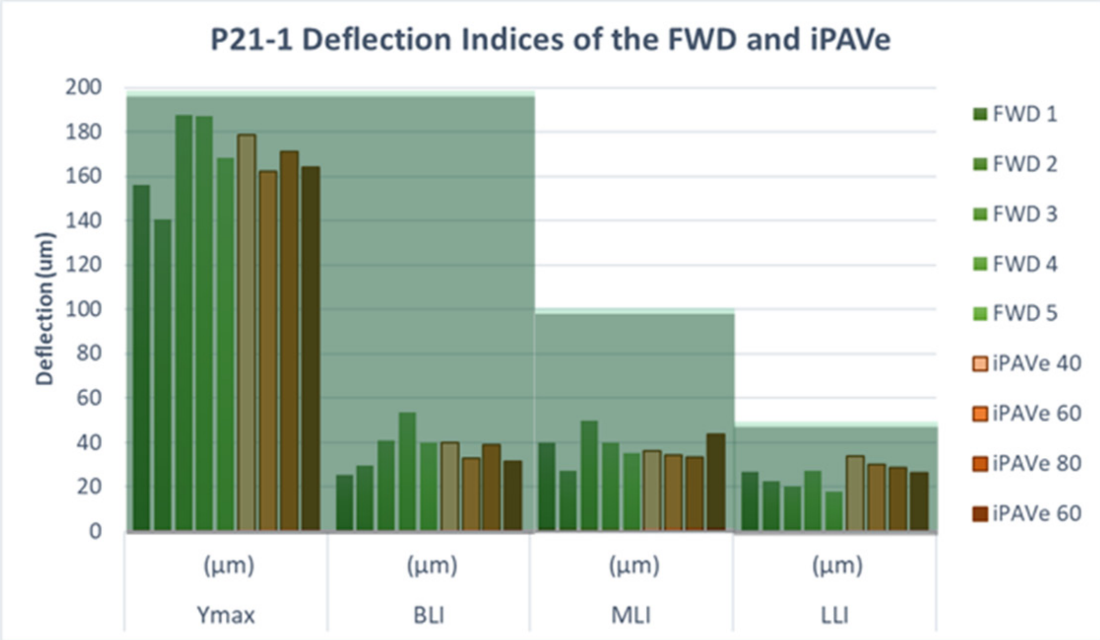

Figure 8: Median deflection bowl indices for P21-1

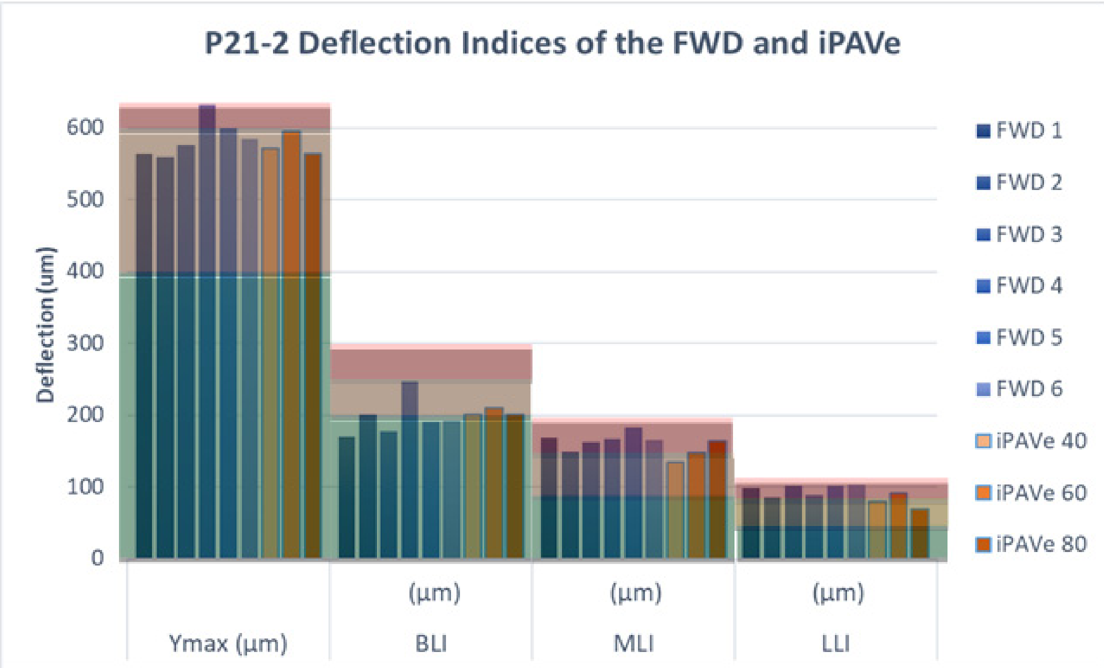

Figure 9: Median deflection bowl indices for P21-2

The maximum deflection measurements of the iPAVe and FWD are similar for both P21-1 and P21-2 since the same pattern is followed over the 100 m sections. However, the variability of the iPAVe maximum deflection is higher than the FWD. The similarity of maximum deflection measurements between the FWD and iPAVe is better for P21-2 than for P21-1. A similar pattern was found for the other deflection indices.

In conclusion, there are close similarity between pavement layer indices for the iPAVe and FWD. The variability in one metre measurements of the iPAVe is evident in the maximum deflections for both P21-1 and P21-2 as seen in Figure 7 and Figure 10.

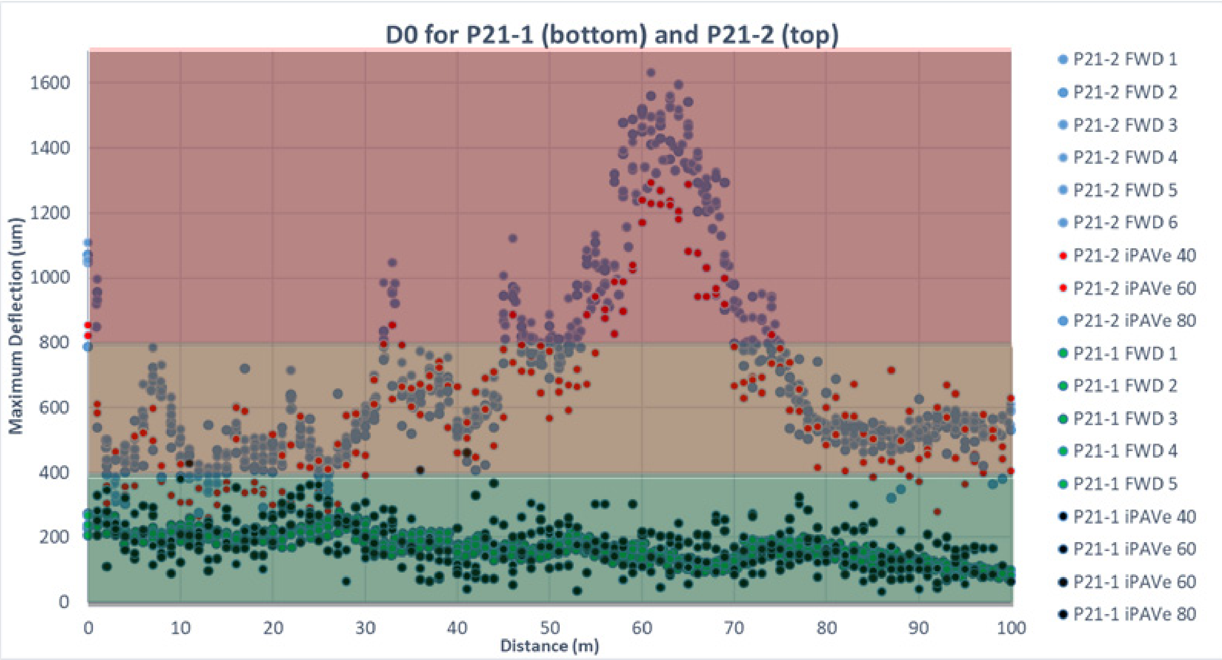

Figure 10: Maximum deflections (D_0) from the iPAVe and FWD along P21-1 (bottom) and P21-2 (top)

4.3 Layer Stiffness

The layer stiffness moduli, that were derived from the pavement profile and individual deflection bowls at each one metre location, provided an estimate on the structural integrity of each layer in the pavement. Pavement layer stiffness moduli were back-calculated using the deflection bowl at each one metre location of P21-1 and P21-2. A representative median stiffness modulus over 100 m was obtained for each test run and are provided in Table 3 and Table 4 for P21-1 and P21-2 respectively.

The layer stiffness moduli back calculated from the FWD deflection measurements for P21-1 has a high variance for most layers where the iPAVe shows a lower variance, especially for the stabilized subbase (layer 2). The difference in stiffness moduli for P21-2 is less than for P21-1 with the exception of layer 2 where the FWD and iPAVe differ by a factor of two for iPAVe 40 and iPAVe 60. The iPAVe produces a slightly higher subgrade stiffness modulus than the FWD for both P21-1 and P21-2.

Table 3: Median layer stiffness moduli for P21-1

	Layer Stiffness (MPa)			
Test	**1**	**2**	**3**	**4**
FWD 1	4500	1100	100	210
FWD 2	5000	1600	60	250
FWD 3	4500	800	90	200
FWD 4	5500	1350	50	210
FWD 5	4500	1000	80	205
iPAVe 40	6500	1000	60	220
iPAVe 60	4500	1200	50	280
iPAVe 80	5500	1100	80	250
iPAVe 60	5750	1000	100	220

Table 4: Median layer stiffness moduli for P21-2

TEST	Layer 1 (MPa)	Layer 2 (MPa)	Layer 3 (MPa)	Layer 4 (MPa)	SG (MPa)
FWD 1	1500	180	40	50	120
FWD 2	1800	150	40	40	120
FWD 3	1400	150	50	50	120
FWD 4	700	160	60	40	130
FWD 5	1500	150	35	45	120
FWD 6	1600	150	40	40	120
iPAVe 40	1100	300	50	40	140
iPAVe 60	1200	300	55	40	150
iPAVe 80	1400	140	70	80	120

4.4 Structural Capacity

Layer stiffness moduli, in combination with the pavement layer thickness, material properties, traffic loading and transfer functions were assigned to each one metre location of P21-1 and P21-2. The pavement was analysed for each location and each test run using the Rubicon Toolbox mechanistic empirical method. The results from this analysis provided an estimated bearing capacity which is expressed in MESA. The estimated structural capacity for each one metre on P21-1 and P21-2 is presented in Figure 11.

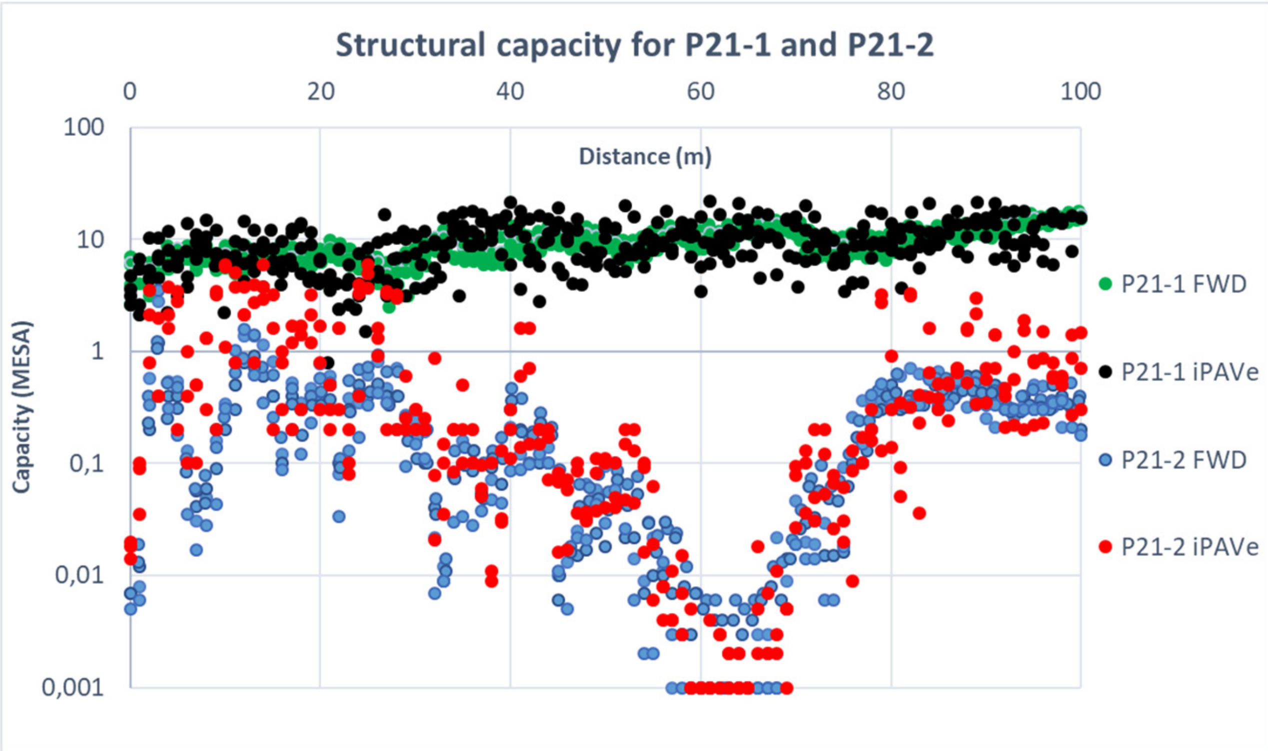

Figure 11: Structural capacity for P21-1 (top) and P21-2 (bottom) using FWD and iPAVe measurements

The estimated structural capacity, calculated using the iPAVe and FWD deflection measurements, respectively is similar for P21-1 and P21-2. However, the variance on the iPAVe calculated structural capacity of P21-1 is high with some results being over or underestimated compared to those of the FWD. However, the majority of capacity results for the iPAVe are in line with those of the FWD for P21-2.

In general, there is little difference between the estimated structural capacity for P21-1 and P21-2, although more similarity can be seen for P21-1. The individual results for each one metre were combined over the 100m for each duplicate test performed for the FWD and iPAVe. Figure 12 shows the median estimated structural capacity and the corresponding median maximum deflection of each test run for P21-1 and P21-2 respectively.

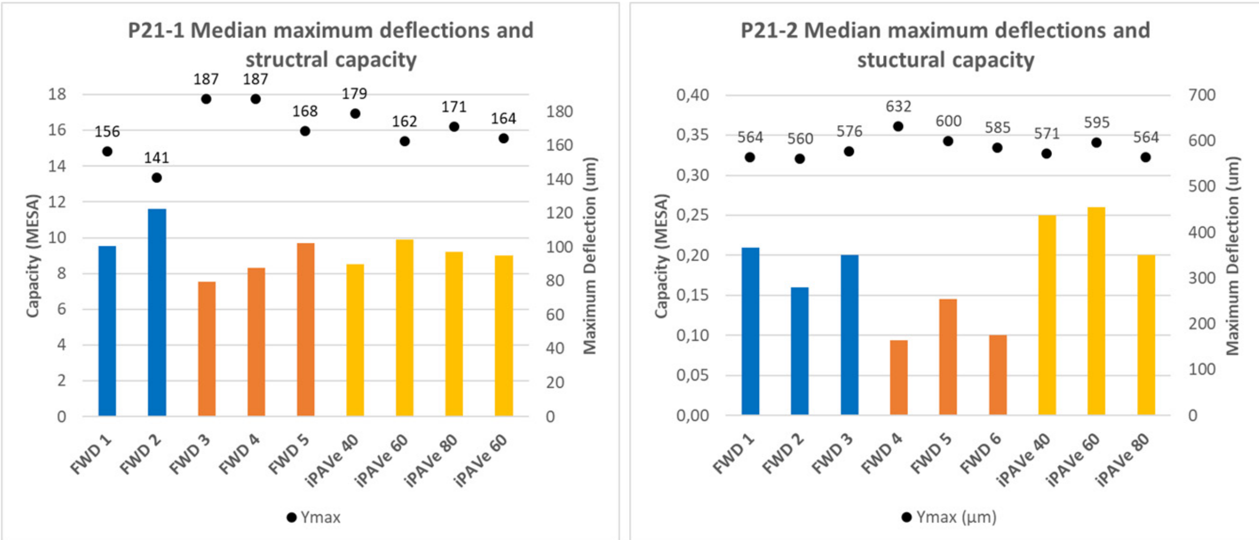

Figure 12: Comparison of FWD and iPAVe maximum deflection and structural capacity for P21-1 and P21-2

Figure 12 confirms that the difference between structural capacity obtained using FWD and iPAVe deflection measurements is less for P21-1 than for P21-2. The iPAVe calculated capacities range from 8.2 to 9.9 MESA and are similar to those of the FWD which range from 7.8 to 11.8 MESA.

The deflections for FWD 2 were obtained during cool conditions and FWD 3 was during hotter temperatures. The FWD testing performed in cooler morning conditions are shown in blue to highlight the fact that temperature also plays a role in the outcome of a mechanistic empirical analysis using deflection measurements. It should be noted that no iPAVe deflection testing were performed in the morning.

The capacities calculated for P21-2 using the iPAVe measurements range from 0.2 to 0.3 MESA and are higher than those of the FWD that ranges from 0.1 to 0.2 MESA. The difference in results of the iPAVe and FWD for sound and distressed pavement sections are however within the same limits and should have negligible influence on the decision making process during either road asset management or pavement design applications.

5. PRACTICAL APPLICATION

While this paper has discussed pavement evaluation using deflection measurements on a micro scale of 100m, this is not the scale at which pavements are evaluated during an assessment or design stage of a project. A more practical approach would be to perform the same exercise on a longer section of road with practical deflection measurement intervals. Hence deflection measurements were performed on a macro scale using the FWD and iPAVe (travelling at 80 km/h) on the same P21 road, but over a distance of 36.5 km. The measurement interval was selected at 50m as per SAPEM Chapter 10 standards, similar to a typical pavement rehabilitation design project. The aim of the practical application is to compare the iPAVe and FWD in terms of pavement evaluation and mechanistic empirical analysis by using design principles that are applied in practice.

The first step was to plot and compare the D_0 and the respective cumulative sum for the iPAVe and FWD measurements. This was done by including the behavioural state limits and structural condition rating as set out in SAPEM Chapter 10 Table 43 and Table 44 respectively. This is illustrated in Figure 13 and Figure 14.

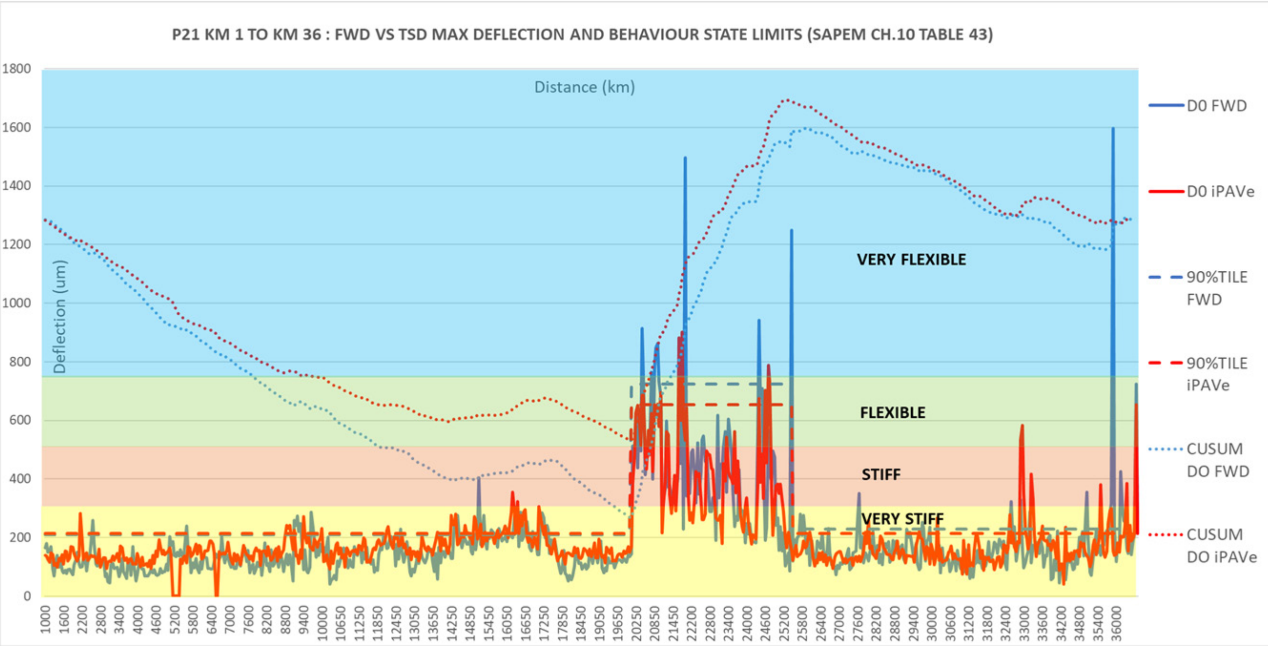

Figure 13: Behavioural state of FWD and iPAVe maximum deflection over 36.5 km

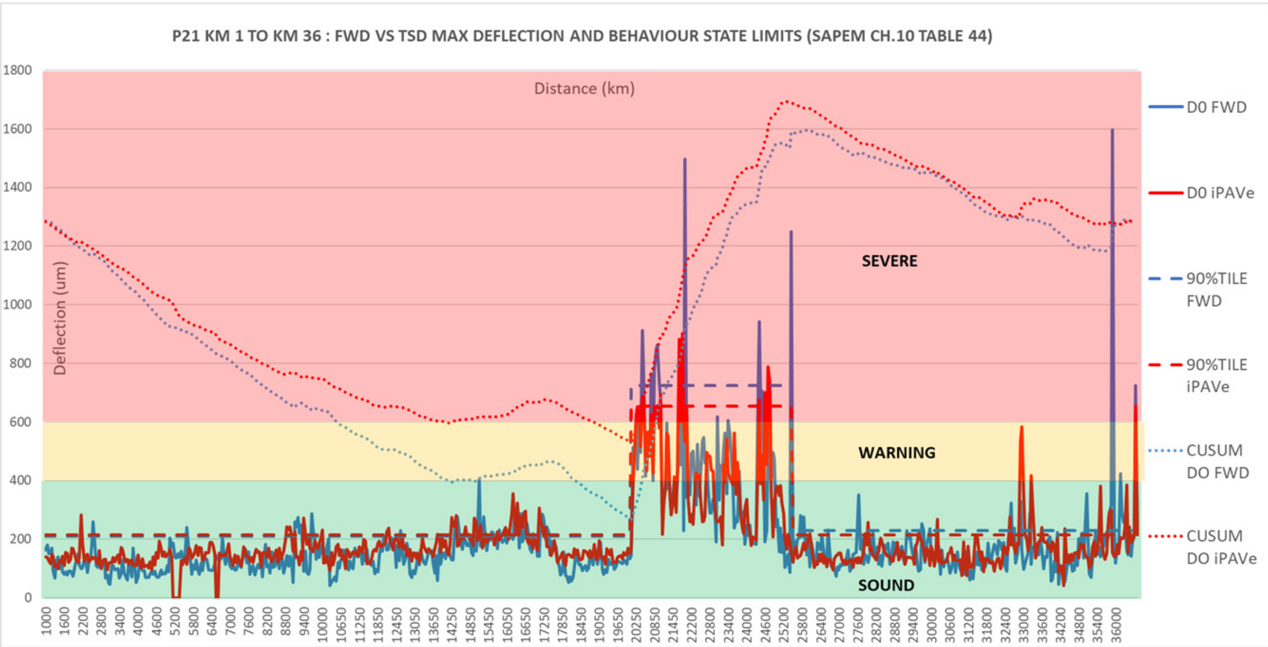

Figure 14: Condition rating of FWD and iPAVe maximum deflection over 36.5 km

The cumulative sum of the iPAVe and FWD measurements resulted in three clear uniform sections in terms of structural condition. The first and the third section can be assumed to be in sound structural condition and the second in distressed condition. P21-1 is located in the first uniform section and P21-2 is located in the second uniform section.

In addition, the 90th percentile representative limit is illustrated for each uniform section identified as would be done during the evaluation and design of a typical Class B road. The closest actual deflection bowls to the 90th percentile maximum deflection for each uniform section are plotted in Figure 15 to illustrate the difference between the iPAVe and FWD deflection bowl measurements.

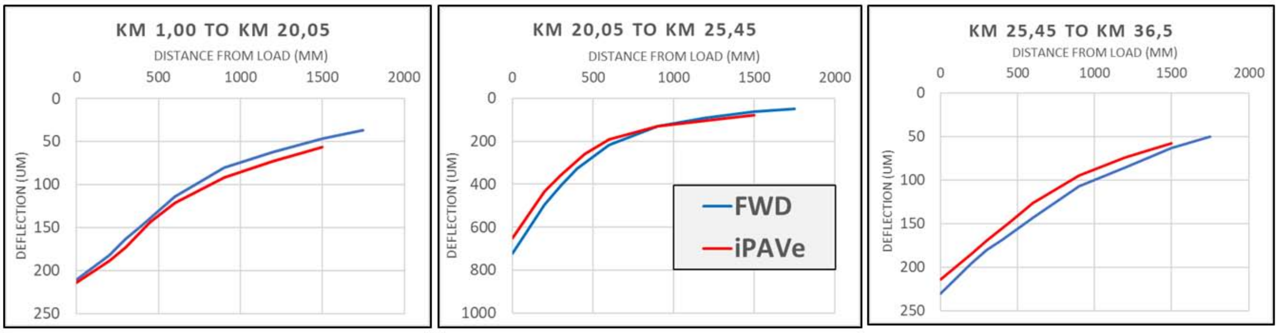

Figure 15: Comparison of the 90th percentile FWD and iPAVe deflection bowls for each uniform section

Each of these deflection bowls were used to back-calculate pavement layer stiffness moduli for each uniform section. The stiffness moduli, pavement profile and traffic loading used in this study was populated into a mechanistic empirical analysis to determine the structural capacity of each uniform section using for the iPAVe and FWD data. The results of the analysis are shown in Table 5.

Table 5: Comparison of iPAVe and FWD derived layer stiffness moduli and estimated structural capacity

Test	Uniform Section	Back calculated Stiffness's (MPa)					Capacity (MESA)
		Layer 1	Layer 2	Layer 3	Upper Subgrade	Substratum	
FWD	KM 1 TO KM 20,05	6000	960	70	120	210	8,5
iPAVe	KM 1 TO KM 20,05	5900	980	80	120	160	8,6
FWD	KM 20,05 TO 25.45	750	160	40	100	120	0,1
iPAVe	KM 20,05 TO 25.45	700	140	140	100	90	0,1
FWD	KM 25,45 TO 36.50	6900	990	80	100	130	9,1
iPAVe	KM 25,45 TO 36.50	6500	980	120	110	150	9,7

The practical application exercise highlights that there is very little difference between the mechanistic empirical analysis results that were derived from iPAVe and FWD deflection measurements. This hold true for distressed and sound condition pavements. It is therefore evident that iPAVe technology could, in fact, be utilised for project level investigations in the absence of FWD deflection data.

6. CONCLUSIONS

- On a micro level of 100 m road length and one metre testing interval the intact or sound condition pavement with lower maximum deflection measurements, the iPAVe shows some variance when compared to the FWD results.
- Good correlation was observed between the maximum deflection measurements of the iPAVe and FWD for the cracked pavement with higher maximum deflection measurements.
- The LLI values derived from the iPAVe deflections was lower than those derived from the FWD. This finding needs to be investigated further.
- Layer stiffness and structural capacity calculated using the iPAVe deflections are similar to the results calculated using the FWD.
- Benchmarking of deflection measurements from the FWD and iPAVe data over the 36.5 km section provide similar results for the D_0, BLI, MLI, LLI and cumulative sum method for determining uniform sections. The 90th percentile benchmark indices of the FWD and iPAVe are also well correlated.
- The back-calculation of pavement layer stiffness, using the closest deflection bowls to the 90th percentile maximum deflection of the uniform sections identified, produces comparable results for the FWD and iPAVe. The subsequent mechanistic empirical analysis for the three (3) uniform pavement sections along the 36.5km section of P21 shows a very high structural capacity correlation.
- It has been shown that deflection measurements from the iPAVe is suitable for use as a proxy continuous FWD during project level pavement evaluations.

7. RECOMMENDATIONS

- Pavement structural evaluation results, using iPAVe and FWD deflection measurements, correlate well for pavements with thick asphalt surfacing and/or base layers. It is recommended that a similar study be performed on granular and cemented base pavements with thin surfacing as well as on concrete pavement structures.
- A further study should be undertaken to investigate a methodology to reduce the measurement “noise” without affecting the validity of the data.
- The duplicate iPAVe deflection measurements, to be compared to the FWD deflections, should all be performed at the same speed to remove speed as a variability factor.
- It is recommended that the discrepancy in lower pavement layer deflection, i.e. subgrade layer stiffness estimation, between the iPAVe and FWD be further investigated.
- It is recommended that iPAVe technology be used for both network and project level pavement investigations with clear advantages in terms of higher measurement frequency, assessment speed and safety.

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