A Study of the FWD Deflection Characteristics of Composite and Sandwich Pavements

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ABSTRACT: A study was carried out on the falling weight deflectometer (FWD) deflection data obtained from road pavements in the South Coast region of Queensland. The pavement structures consist of the conventional asphalt granular pavement, composite and "sandwich" pavements construction. The FWD deflection characteristics of the three pavement structures were studied using a simplified deflection model (SDM). The mathematical expression for the SD model is $Y = K_1 \exp(-X / K_2) + Y_0$. The exponential curve was found to have the desired characteristics which match the FWD deflection bowls. In the equation, *Y* is the FWD deflection in microns and *X* is the radial distance in millimeters. The coefficients K_1 and K_2 of the model describe the structural characteristics of the pavements. The results indicate that the coefficient K_1 and K_2 are unique for the three pavement types with relatively thin asphalt and sealed coat layers. The study suggests that the coefficient K_1 is closely related to strength of the subgrade and K_2 is dictated by the deflection ratio, *DR*, of the FWD deflection curve. The deflection data generated with SDM were compared with the deflection results obtained from ELSYM5. The study showed that SDM models the FWD deflection more accurately for granular pavements with thin surfacing layers.

KEY WORDS: Simplified deflection model, composite pavement, "sandwich" pavement, FWD deflection, ELSYM5

1 INTRODUCTION

In this study, thin surfacing pavement is described as having the top bituminous surfacing layer of less than 40 mm in thickness. Thin sprayed seal and asphalt surfacing are widely used in Australia for providing an all weather road network in the country with land size of about 7 million square kilometers. Between the two surfacing types, sprayed seal is more commonly used by state and local governments for rural road construction. In 1998, the total length of public road in Australia exceeded 800,000 km. Of this length, 319,000 km (or 40%) had a bituminous or concrete sealed surface (Austroads, 2000). Between about 80 and 90 percent of Australia all weather road network is surfaced with sprayed seal (Oliver, 2006).

Queensland Department of Transport and Main Roads (DTMR) South Coast Region and Gold Coast City Council maintain a total of about 3,651.6 km of paved roads. The paved roads are either sprayed seal or asphaltic concrete. Table 1 provides the breakdown of the length of the paved roads in the study area.

Table 1 : Road networks within the study area

Road Network(km)	DTMR- South Coast Region	Gold Coast
Spray Seal	718.6	644.3
Asphalt	287.7	2001.0
Total Paved Road	1006.3	2645.3

FWD is used by the road agencies for network level deflection survey for assessing the rate of pavement deterioration and to determine the timing for rehabilitation. Deflection basin parameters from FWD testing device are used extensively for assessing the structural integrity of a pavement and to back calculate the in situ layer moduli of a pavement. Pavement structural deformation is greatly dependent on the performance of the various pavement layers and the quality of the pavement subgrade. Inaccurate back analyzed pavement layer modulus can result if poor matching of the deflection data occurs. This can happen if the pavement analysis software programs do not have the capability to match the deflections at distances from the FWD loading location. This is particularly true for pavements with thin surfacing layers.

Because of the great extent of the pavements in Australia were constructed with either thin sprayed seal or asphalt surfacing, it is necessary to understand the structural performance of these pavements which differ markedly from those of thick asphaltic concrete surfacing. This paper presents a new approach using a Simplified Deflection Model (SDM) for modeling the FWD deflection curve for granular pavements with thin surfacing layers. The deflection data generated with the SDM were compared with the deflection results obtained from ELSYM5.

The coefficients K_1 and K_2 of the SD model were analyzed for the deflection curves obtained from composite, “sandwich” and granular pavements with thin asphalt or sealed coat surfacing. In the composite pavements, the granular road base and the subbase were treated with cement. For the “sandwich” pavement construction, a granular layer was introduced on top of the cement treated road base and sub base and the granular layer forms a “sandwich” between the top asphalt layer and the bottom cement treated base layer.

2 TESTING PROGRAM

A study was carried out on the falling weight deflectometer (FWD) deflection data obtained from road pavements along the Cunningham Highway in South Coast Queensland Region. The section of the highway included in the study has a total length of 50 kilometers. The pavement structures consist of the conventional asphalt granular pavement, composite and “sandwich” pavements construction. In the composite pavements, the granular road base and the subbase were treated with cement. For the “sandwich” pavement construction, a granular layer was introduced on top of the cement treated road base and sub base and the granular layer forms a “sandwich” between the asphalt layer and the cement treated base layers. The FWD data were also collected from the test site along Dudgeon Drive in Gold Coast.

The FWD deflection measurements were taken at 25 meters interval along the outer wheel path of a road lane. The load level used for the FWD drops was 50kN, which corresponds to a load pressure of approximately 700 kPa. Seismic geophones which monitor the deflections were placed at 0 mm, 200 mm, 300 mm, 450 mm, 600 mm, 900 mm and 1500 mm offsets to measure the full pavement deflection basin. Readings from 8 geophones and including the one located at the centre of the loading plate were reported.

During the deflection test, the temperature of the asphalt was measured at an appropriate time intervals. The deflection data were corrected to the average working temperature of the pavement for the particular location. The average working temperature of the pavement is referred to as the Weighted Mean Annual Pavement Temperatures (WMAPT). The WMAPT are grouped into 4 temperature zones in the state of Queensland (QMR, 1992). The deflection data were multiplied by the adjustment factors to correct for the difference between the measured field temperatures and the WMAPT for the particular temperature zone. The respective adjustment factors were determined from Figure 10.2 in Austroads (Austroads, 1992) on the Temperature Correction for Deflection and Curvatures.

3 MODELING OF FWD DEFLECTION

In the previous study carried out by Chai and Kelly (2008), it was concluded that it was possible to model the FWD deflection data obtained from the Southeast Queensland's long term pavement performance (SEQ-LTPP) sites using an exponential curve in a mathematical form of $Y = K_1 \exp(-X/K_2) + Y_0$. The exponential curve was found to have the desired characteristics which match the FWD deflection bowls and was termed as a simplified deflection model (SDM). The simplified deflection model and the model parameters are explained as follows:

$$Y = K_1 \exp\left(-X / K_2\right) + Y_0 \tag{1}$$

where,

Y = FWD deflection in micron;
X = radial distance in millimeters from the load axis;
K_1, K_2 = structural parameters
Y_0 = a constant;

In the study, more than 600 FWD deflection data obtained from the 65 SEQ-LTPP sites have been modeled using the simplified deflection model. The results for the 11 LTPP sites comprising all types of pavement constructions are reproduced in Table 2 which provides a summary of the structural parameters K_1 and K_2 for the deflection models. The FWD deflection basins obtained from field testing and that generated by the simplified deflection model for several SEQ-LTPP sites are presented in Figure 1 to Figure 4.

The LTPP pavements consist of thin sprayed seal (10-25mm) and asphalt pavement (25-50mm) surfacing with either granular or cement stabilized road base layers vary from 150mm to 400mm. The LTPP sites also consist of pavements with subgrade CBR values of less than and greater than 5. The traffic volumes in the local roads are considered low to moderate with traffic count ranging from 250 AADT (with cumulative equivalent standard axle loading of less than 0.30 million standard axle/year) to 10,000 AADT (with cumulative equivalent standard axle loading of greater than 0.30 million standard axle/year). The standard axle loading consists of a dual-wheeled single axle, applying a load of 80kN (Austroads, 2004).

It is evident that the parameter K_1 decreases as the stiffness of the pavement road base increases as a result of cement stabilization. Contrary to K_1, parameter K_2 shows an increasing value for the pavements with stabilized base layers because of the increase of the stiffness of the road base layer. The study also shows that subgrade strength has a significant influence on the FWD deflection parameter D_0 and the structural parameter K_1 for low volume road pavements with relatively thin surfacing layers and granular road base. A large percentage of the deflection D_0 is contributed by the subgrade and in most cases the percentage can be more than 70 percent. Moreover, the life of the pavements is governed by the vertical strain on top of the subgrade layer. Another observation can be made is that the parameter Y_0 relates closely to the deflection at the last FWD sensor.

Table 2**:** Summary of the K_1, K_1 and Y_0 (Chai & Kelly, 2008)

LTPP Site	Stiffness Modulus (MPa)			Pavement	K_1	K_2	Y_0
	Surfacing	Road base	Subgrade				
RSC05	2500	1500	130	composite	408	385	8
GCC04	2000	1000	170	composite	393	556	6
GCC13	2500	2000	180	composite	310	733	18
LCC01	2000	350	120	granular	616	392	9
LCC05	2500	450	200	granular	421	383	9
CCC05	2500	450	250	granular	466	402	2
LCC08	2000	400	150	granular	608	318	14
CCC10	2000	450	120	granular	715	368	22
CSC08	2500	450	200	granular	516	531	38
GCC03	2000	350	35	granular	1484	414	30

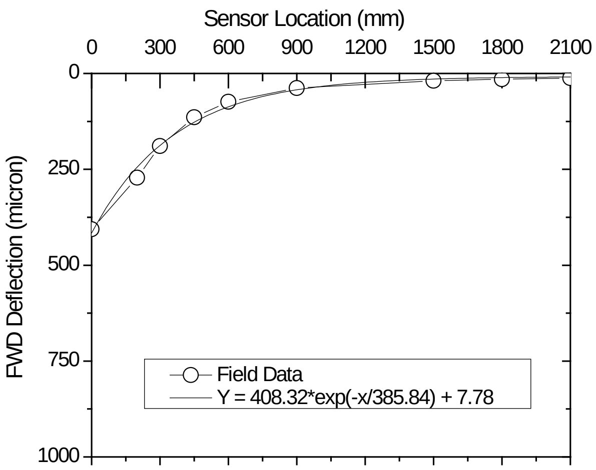

Figure 1: Deflection at LTPP No: RSC05

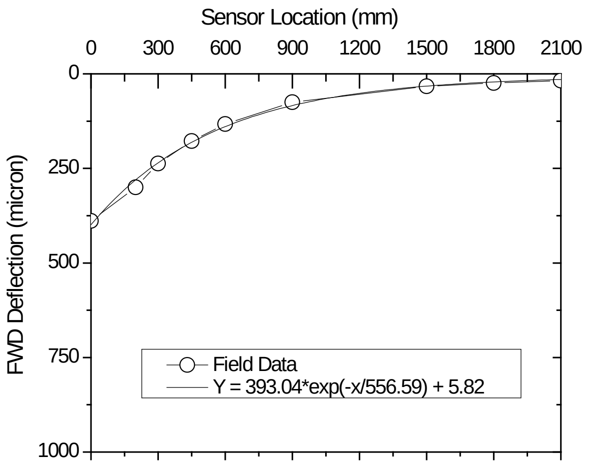

Figure 2: Deflection at LTPP No: GCC04

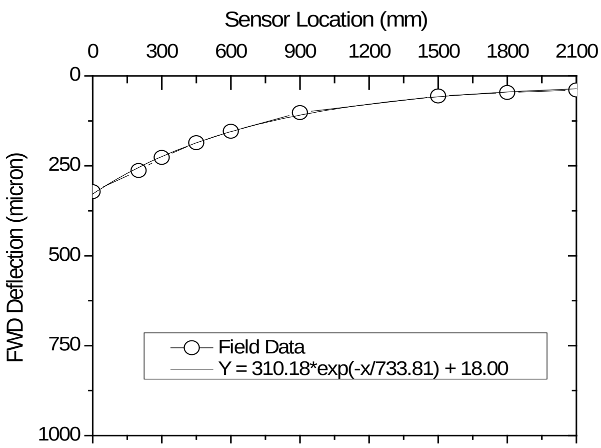

Figure 3: Deflection at LTPP No: GCC13

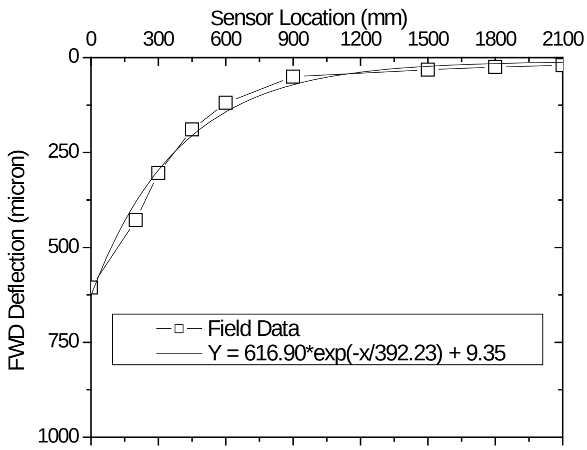

Figure 4 Deflection at LTPP No:LCC01

In the current study, 200 FWD deflection data obtained from the road sections along Dudgeon Drive and Cunningham Highway have been modeled using the SD model. The deflection data were also modeled using ELSYM5 (ELSYM5, 1986) program in order to compare the results generated by SD model approach.

The pavements modeled in the study consisted of thin sprayed seal (10-25mm) and asphalt pavement (25-50mm) surfacing with either granular, cement stabilized road base layers vary from 150mm to 400mm. In the sandwich pavement construction, a granular layer was introduced on top of the cement treated road base and sub base. The pavement subgrade CBR values vary from 3 to 17 percent. The traffic volumes along Dudgeon Drive in the local roads are considered low and that along Cunningham Highway is moderate with traffic volume around 4,500 vehicles per day in both directions, with approximately 22% heavy vehicles.

ELYSYM5 is a computer program that will determine the various component stresses, strains, and displacements along with principal values in a three-dimensional ideal elastic layered pavement system. The layered pavement is loaded with one or more identical uniform circular loads normal to the surface of the pavement. The pavement analysis software program was developed at the Institute of Transportation and Traffic Engineering (ITTE) at the University of California at Berkeley. It is based on the LAYER5 elastic layered computer model, with the ability to consider multiple loads as well as the presence of a rigid base below the subgrade (ELSYM5, 1986). The global coordinate system adopted in the study is a three-dimensional cartesian system shown in the pavement model in Figure 2 (Austroads, 2008).

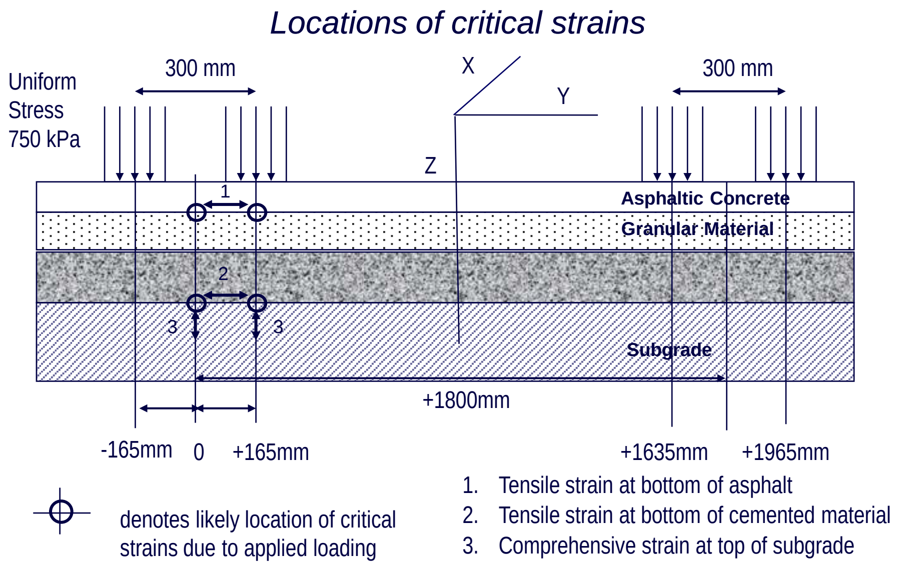

Figure 5: Pavement model with three-dimensional cartesian system (Austroads, 2004)

3 DISCUSSIONS OF RESULTS

The deflection data obtained from several sections of Cunningham Highway and Dudgeon Drive were modeled using the SD model and ELSYM5. The results are presented in Table 3. The percentage errors are presented to indicate the deviation may occur when using the two methods in the analysis. The SD model predicted FWD deflection reasonably well with the percentage errors in most cases are less than 10 percent. ELSYM5 generated good prediction of deflection for sensor D_0, D_1 and D_2 in the different pavement types. However, large deviation from the actual deflection was recorded for sensors D_3, D_4, D_5 and D_6. The errors were computed to be between 261% to as high as 886%. This is particularly true for granular pavements with thin surfacing layers.

An explanation can be made is that large deflection ratio (*DR*) for D_3/D_4 and D_4/D_5 were recorded for this pavement type and elastic layer theory would not be able to model the deflection with such large deflection ratio. The deflection ratio is defined as follows:

$$\text{Deflection Ratio, } DR = D_i/D_j \quad (2)$$

where

D_i = FWD deflection data at Sensor No.i (micron);
D_j = FWD deflection data at Sensor No.j (micron)

Table 3: Pavement response for different pavement types

		FWD Sensor Locations (mm)						
Road Name /thickness (mm)	**Pavement type**	**0**	**200**	**300**	**450**	**600**	**900**	**1500**
Case 1 Dudgeon Drive	**Granular pavement**	**D0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
Asphalt 35mm Granular 155mm Subgrade CBR 3%	FWD	2382	1818	1296	720	355	43	27
	DR	1.00	1.31	1.40	1.80	2.05	8.25	1.59
	SD Model	2257	1785	1266	651	332	40	27
	Difference (%)	5.2	1.8	2.3	9.5	6.4	6.9	0
	ELSYM5	2540	1640	1239	881	663	424	307
	Difference (%)	6.6	9.7	4.3	22.3	86.7	886.0	
Case 2 Dudgeon Drive	**Granular pavement**	**D0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
Asphalt 40mm Granular 210mm Subgrade CBR 3%	FWD	2159	1680	1270	800	462	120	58
	DR	1.00	1.28	1.32	1.58	1.73	3.85	2.06
	SD Model	2120	1709	1222	838	440	129	55
	Difference (%)	1.8	1.7	3.8	4.7	4.8	7.5	5.2
	ELSYM5	2250	1473	1140	848	660	434	317
	Difference (%)	4.2	12.3	10.2	6	42.8	261.6	446.5
Case 3 Dudgeon Drive	**Granular pavement**	**D0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
Asphalt 35mm Granular 255mm Subgrade CBR 9%	FWD	1228	971	725	462	285	104	56
	DR	1.00	1.26	1.33	1.56	1.62	2.74	1.85
	SD Model	1261	992	737	454	272	108	55
	Difference (%)	2.6	2.2	1.6	1.6	4.5	3.6	1.1
	ELSYM5	1222	655	457	320	242	158	116
	Difference (%)	0.5	32	37	31	51	52	107
Case 4 Dudgeon Drive	**Granular pavement**	**D0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
Asphalt 35mm Granular 155mm Subgrade CBR 17%	FWD	698	531	361	199	102	20	8
	DR	1.00	1.31	1.47	1.81	1.95	5.1	2.5
	SD Model	758	514	396	216	109	21	8
	Difference (%)	8.6	3.2	9.7	8.5	6.8	5.0	0.0
	ELSYM5	706	345	224	147	108	70	53
	Difference (%)	1.1	35.0	37.9	26.1	5.9	250.0	562.0

Table 3: Pavement response for different pavement types (continued)

		FWD Sensor Locations (mm)						
Road Name /thickness (mm)	**Pavement type**	**0**	**200**	**300**	**450**	**600**	**900**	**1500**
Case 5 Cunningham Hwy	**“Sandwich” pavement**	**D0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
Sprayed Seal 14mm Granular 250mm Cement treated subbase 200mm Subgrade CBR 10%	FWD	572	407	328	244	181	149	47
	DR	1.00	1.40	1.24	1.34	1.35	1.21	3.17
	SD Model	562	408	314	234	175	99	45
	Difference (%)	1.7	0.2	4.2	4.0	3.3	9.2	4.2
	ELSYM5	558	266	208	179	161	127	101
	Difference (%)	2.4	34.6	36.5	26.6	11.0	16.5	114.8
Case 6 Panoramic Drive	**Composite pavement**	**D0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
Asphalt 50mm Cement treated base 200mm + granular Subbase 150mm Subgrade CBR 10%	FWD	406	272	189	114	74	38	19
	DR	1.00	1.49	1.43	1.65	1.54	1.94	2.00
	SD Model	411	282	193	111	75	39	19
	Difference (%)	1.7	0.2	4.2	4.0	3.3	9.1	0.0
	ELSYM5	394	243	194	154	126	89	66
	Difference (%)	2.9	2.6	35.1	70.2	134.2	247.3	240

For the deflection data collected from Dudgeon Drive, it can be observed that the deflection ratio (DR) between sensors D_0/D_1, D_1/D_2 *and* D_2/D_3 range from 1.26 to 1.81. The *DD* between sensors D_3 and D_4 ranges from 1.62 to 2.05. Between Sensor D_4 and D_5, the *DR* value varies from 2.74 to 8.25 and is observed to be particular high when compare with the composite and “sandwich” pavements.

The Deflection Ratio versus the FWD sensor locations for all the pavement types is presented in Figure 11. For both the sandwich and composite pavements, the Deflection Ratio for all sensors are nearly constant at an average value of about 1.50 and the curves show a linear pattern. On the other hand, the other three curves for the granular pavements are non linear and the DR value increases as the offset from the FWD load location increases. These are the unique characteristics of FWD deflection curve recorded for pavements with thin bituminous surface on granular road base within the study area in Southeast Queensland. The non linearity observed in the DR versus offset curve is a logical explanation for the elastic layer theory not been able to model the deflection curve effectively.

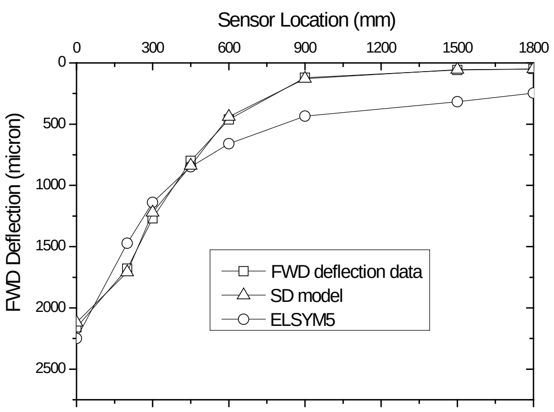

Figure 6: Dudgeon Drive – Case 1 deflection

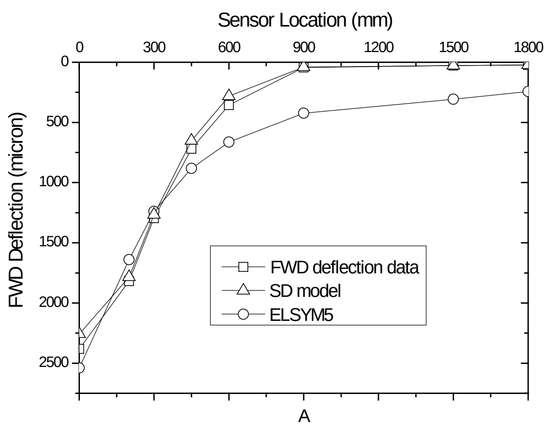

Figure 7: Dudgeon Drive – Case 2 deflection

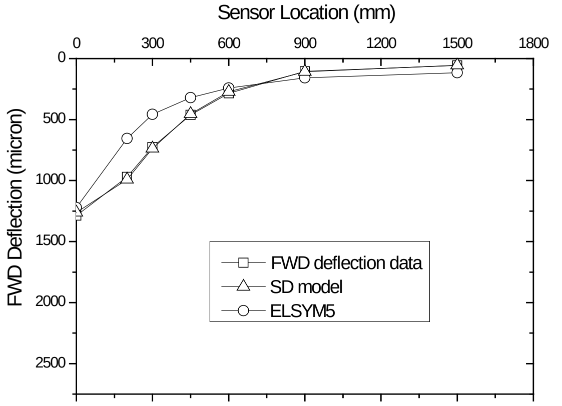

Figure 8: Dudgeon Drive – Case 3 deflection

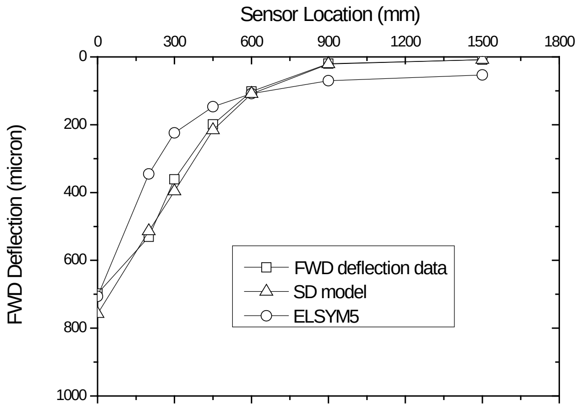

Figure 9: Dudgeon Drive – Case 4 deflection

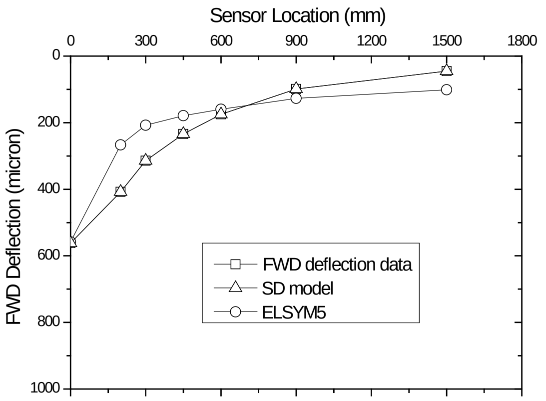

Figure 10: Cunningham Highway
(“Sandwich” pavement)

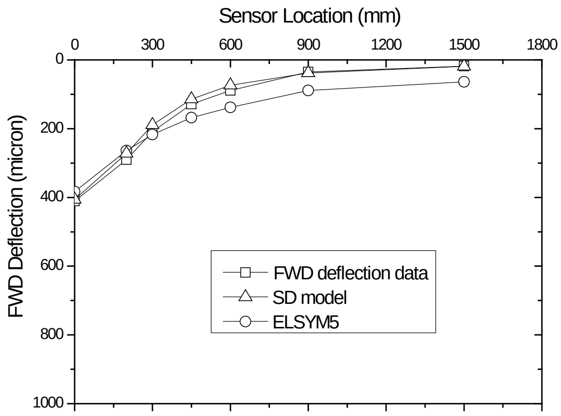

Figure 11: Cunningham Highway
(Composite pavement)

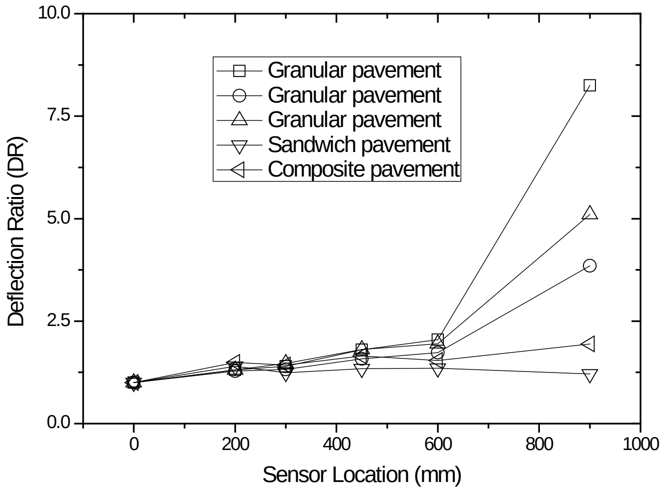

Figure 12: Deflection ratio versus sensor location

The implication of these observations on the computation of the pavement structural number of the granular pavements with thin surfacing is discussed in the following paragraphs. To define the bearing capacity of a pavement, HDM-III model (Watanatada, Paterson and Bhandari, 1987) adopts the modified structural number or *SNC*. The modified structural number is defined as a linear combination of the layer strength coefficient *ai* and thickness *Hi* of the individual layers above the subgrade, and the contribution from the subgrade is denoted by *SNSG* as follows:

$$SNC = 0.0394\sum_{i=1}^{n} aiHi + SNSG \qquad (2)$$

where,

a_i	=	the strength coefficient of the i^{th} layer as defined in the HDM III Manual Volume 1 pages 77 to 79 in Table 4.3 and Figure 4.3(a) and (b);
H_i	=	the thickness of the i^{th} layer provided that the sum of thickness, Hi is not greater than 700mm, in mm;
N	=	the number of pavement layers;
SNSG	=	the modified structural number contribution of the subgrade, given by: $3.51 \log_{10} CBR - 0.85 (\log_{10} CBR)^2 - 1.43$; and
CBR	=	the California Bearing Ratio of the subgrade at in-situ conditions of moisture and density, in percent.

For network level evaluation of pavement condition, D_{900} deflection data obtained from FWD testing is often used to compute the in-situ subgrade *CBR* value. Unreasonably large CBR values would result because the low recorded D_{900} deflection even though Do deflection is reported to be high for this particular pavement type. This will lead to an error in the calculation of the modified structural number contribution of the subgrade (*SNSG*) and hence the modified structural number (*SNC*) of the pavement. This is because the subgrade CBR value can have great influence on the computation results of *SNC* for thin surfacing granular pavement.

Another interesting observation can be made from the study is that K_1 and the Y_0 are closely related to the deflection values recorded at FWD sensors D_0 and D_{1500} respectively. At sensor D_0, the deflection *Y* is contributed by K_1 and Y_0 as the exponential term $(-X/K_2)$ becomes one when X=0.

4 CONCLUSIONS

The FWD deflection characteristics of the three pavement structures namely granular, sandwich and composite pavements with thin surfacing layers were studied using the Simplified Deflection model (SDM) in the form of $Y = K_1 \exp(-X/K_2) + Y_0$. The SD Model was found to have the desired characteristics which match the FWD deflection basins reasonably well for three pavement types. The structural parameters K_1 and K_2 of the deflection model may be used to evaluate the structural characteristics of pavements. The coefficient K_1 and K_2 are unique for the three pavement types with relatively thin asphalt and sealed coat layers. The study suggests that the coefficient K_1 is closely related to strength of the subgrade and K_2 is dictated by the deflection ratio, *DR*, of the FWD deflection curve.

The deflection data generated with the SD Model were compared with the deflection results obtained from ELSYM5. The study showed that SDM approach models the FWD deflection more accurately for granular pavements with thin surfacing layers. ELSYM5 could not model the FWD deflection effectively and the possible engineering explanations are as follows:

- Large Deflection Ratio (*DR*) for D_3/D_4 and D_4/D_5 were recorded for the granular pavements and elastic layer theory would not be able to model the deflection with such large deflection ratio.
- The *DR* versus the FWD sensor location curve for the granular pavements exhibits non linear trend and the DR increases exponentially as the offset from the FWD load location increases. The non linearity observed in the *DR* versus FWD offset curve is a logical explanation and reason for the elastic layer theory not been able to model the deflection curve effectively.
- The FWD load pressure of 700 kPa used in testing the thin granular pavements resulted in a high strain levels within the vicinity of the load location in contrast to the relatively low strain levels at sensors D_{900} , D_{1200} and D_{1500}. The contrasting strain level resulted in a large deflection ratio between the FWD sensors.

The study also shows that the current practice in using D_{900} deflection for calculating the subgrade CBR for the granular pavements could result in unreasonably large computed CBR values. This will lead to an error in the calculation of the modified structural number contribution of the subgrade (*SNSG*) and hence the modified structural number (*SNC*) of the pavement. It is recommended that a new engineering model for CBR prediction would need to be developed for granular pavement with thin surfacing.

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