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Application of Falling Weight Deflectometer (FWD) and Synthetic Fiber in the Asphalt Mixture: A Review

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Abstract: The structural evaluation by using Non Destructive Test (NDT) were used to assess the structural condition of pavement. Through the data obtained from previous studied, this study considered a few parameters. This study aims to analyse the vertical deflection to the load applied and to synthesize the elastic modulus of pavement layer using an application of Falling Weight Deflectometer (FWD). The trend of the vertical deflection can be predicted by using various types of software where it is collected the characteristic design of the pavement through back calculation. The addition of synthetic fiber into asphalt pavement could increase the strength of the pavement as it has very high tensile strength. Synthetic fiber were design to enhance the current mix design pavement as fibers will not melt when mix into asphalt because it has strength and durability to withstand in high and low temperature. The combination of synthetic fiber increases the properties of elastic modulus in the pavement mixture design compared to without combination of synthetic fiber. The elastic modulus result shown that there is correlation between the permanent deformation and the elastic modulus where the better the elastic modulus the better the pavement could resist the permanent deformation.

Keywords: Falling Weight Deflectometer (FWD), Synthetic Fiber, Elastic Modulus, Vertical Deflection, Permanent Deformation

1. Introduction

Specifically, the pavement trend in Malaysia usually familiar with Hot Mix Asphalt or also known as HMA that contained with a few combinations of mixture such as sand, stone, aggregate or gravel that mixed thoroughly with asphalt cement. A few defects that usually occurred due to heavy load traffic with the changes of weather could causes rutting, fatigue and cracking which will give major effect on the performance of the pavement. From the consequence, decreasing performance of pavement could increase the cost of maintenance. In terms to reduce the cost of maintenance, engineer and scientist put

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a lot of effort through research and development by innovate and introduce additives to mix in asphalt mixture. The materials such as fiber were added into asphalt mixture with the combination of other substances that could enhance the strength and increase the performance of pavement. The mixture of fiber that was added into asphalt known as fiber reinforced asphalt concrete (FRAC). Fiber that mixed with asphalt binder or asphalt mixtures have been largely used to overcome the major problems related to flexible pavements like rutting, fatigue cracking or thermal cracking and ravelling. [1] Basically, fiber in the asphalt mixture or HMA acts as reinforcement but different types of fiber will provide different performance based on the composition of the fibers itself.

The falling weight deflectometer (FWD) were designed to promulgate load pulse to the pavement surfaces which resembles the load produced by rolling wheel. An application of FWD will apply load based on standard axle loads of wheel tracking on the road pavement. Literally after the load applied vertical deformations in a shape of deflection bowl will occur whereas from the deformation, in-situ elastic modulus and the pavement layer can be estimated by the iteration of backcalculation.

2. Materials and Method

In this study, the data was reviewed on the application of Falling Weight Deflectometer (FWD) where the data analyse using backcalculation software program through iterative method. This study also was reviewed on the synthetic fiber to know the improvement of mixture when mixed with fiber compared than control sample which is without fiber contained.

2.1 Falling Weight Deflectometer (FWD)

Falling Weight Deflectometer is a non- destructive instrument used to test structural pavement evaluation. The function of FWD is to measure the vertical deflection on the surface pavement when the load impulse was applied. The response of the pavement system (i.e. pavement deflection) is determined by an array of seven velocity transducers (geophones) positioned at different radial distances from the centre of the loading plate. [2] FWD deflections were determined using the FWD loading background spectral element method for asphalt pavements measured in different fields. [3] The history data of deflection were used to evaluate the damage of pavement causes by thawing period and the structural behaviour of pavement. The data obtained from FWD time history also can be used to indicate the estimation of fatigue damage over the flexible pavement.

Usually starting load applied is 40kN-load which represent standard axel loads of vehicles. FWD also consist of seven geophones or nine geophones which acts as sensors as in Figure 2 and Figure 3 where all these are positioned at designated deflection in millimetres away from the center of the loading plate in every designated section. The load pulse generates away from the center of a circular load plate with size of 300mm from a certain height. Lastly from the deflection basin data will compute into backcalculation by using software to determine all the parameters as the component can be referred in Figure 1.

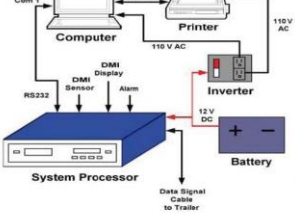

Figure 1: Major component of FWD which control system. [4]

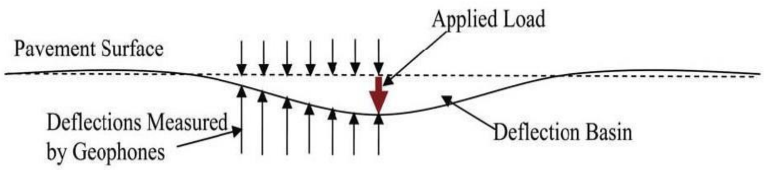

Figure 2: Schematic drawing of deflection basin measured by geophones. [4]

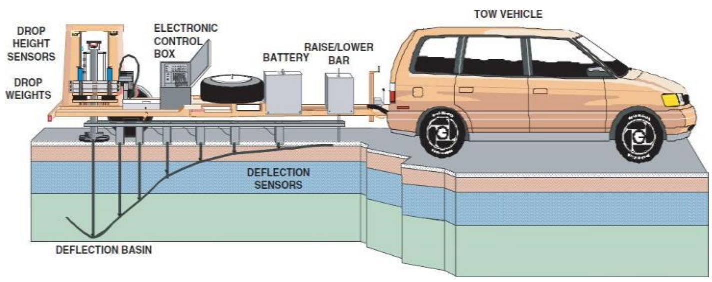

Figure 3: Type of FWD used in study. [4]

2.2 Backcalculation Using Software

Backcalculation is a mechanistic evaluation of pavement structural response that uses the deflections measured with a load test equipment and attempts to match them with the calculated deflections, from an identical simulated load on an equivalent pavement structure, by adjusting the pavement layers moduli. [5] There's three types of backcalculation techniques in terms to determine the layer stiffnesses of pavement where based from the result of deflection basin data. Those three techniques are iteration techniques, database techniques and dynamic backcalculation techniques. Backcalculation were conducted using computer programs. In this study, iteration techniques were chosen as the method for the backcalculation as this study were conducted by using Falling Weight Deflectometer Dynatest 8082. The computer program used by FWD Dynatest 8082 was Evaluation Layer Moduli and Overlay Design (ELMOD®). ELMOD® program were used to determine the modulus of pavement and stress and strain for each layer based on the pavement responses from the sensor used by FWD.

The approach using iterative techniques where the repeated layer moduli were applied until matched the calculated deflection basin which the deflection basin were measured within a tolerance. A few considerations need to take account as this will influence the backcalculation analysis. Temperature adjustment is important as it will influence the HMA moduli. As the stiffness of asphalt concrete frequently change vary to the temperature so temperature control or adjustment is important during conduct the testing. Usually the temperature adjustment in between 20ºC to 27ºC meanwhile, the Poisson's Ratio to calculate the deflection at distance radial from the load is μ = 0.35. The result will be generated by computer program which is ELMOD® for both type of pavement. The data will be compared for in terms of pavement deflections according to load applied, and modulus of elasticity. All these parameters will effect on the judgement for fiber reinforced asphalt concrete effectiveness in terms of reducing maintenance cost of pavement, factor need to be improved for the performance of pavement and to increase strength of pavement.

3. Results and Discussion

The data gained from Falling Weight Deflectometer (FWD) whereas focused on vertical deflection and elastic modulus of the flexible pavement and also the elastic modulus of synthetic fiber that were tested on laboratory testing. The data gained from previous studied that are collected, recorded, analysed and discussed through this chapter. In order to make better understanding the data were presented in graphs and tables. Some of the analysis was analysed by using different types of software used during the testing using FWD in certain areas.

3.1 Vertical Deflection

The following vertical deflection data below on Table 1 were tested by using software computer program BISDEF where it is tested on 7 different project sites with approximately 7 kilometre and 105 locations on flexible pavement structural performances. The trend of deflections for all projects almost same as it is measured away from pavement load. This showed that the deflection under the load was a representative of surface layer modulus, and this trend appeared to indicate that the response of the inflexible pavement was dominated by lower layer and then, made the pavement surface layer moduli along with the location to be identical. [5]

Table 1: Summary data of deflection ranges for all project.

Project	Linear Analysis (μm)	Non-Linear Analysis (μm)
1	320 – 880	350
2	380 – 570	380
3	500 – 650	500
4	500 – 930	800
5	300 – 800	550
6	470 – 600	550
7	400 - 500	500

The deflection basin for project 1 where average maximum deflection between range 320 to 880μm for linear elastic behaviour while for non-linear analysis is 350μm. It is show that bot linear and non-linear analysis had similar trends but non-linear analysis much lower its dynamic deflection compared to linear elastic behaviour. [5] The maximum deflection on project 2 where the linear elastic value between range 380 to 570μm while 380μm for non-linear analysis. The similarity these data can be referred at project 3 Table 1 where the range for linear elastic behaviour is 500 to 650μm and about 500μm for nonlinear analysis. The maximum deflection ranges at D_0 (sensor 0) for the sections at the project between 500 and 930μm for linear elastic while for non-linear analysis is 800μm. However, the maximum defections at Project 4 is higher compared to project 1 until 3. The linear elastic behaviour for Project 5 is between 300-800μm while for non-linear analysis behaviour is 550μm. Even the deflection trends at Project 5 were almost similar to Project 4 because there was big gap between Do compared to the other locations. The maximum deflection ranges for Project 6 is 470 to 600μm for linear elastic behaviour while non-linear elastic analysis is 550μm. The analysis on Project 7 shows the linear elastic behaviour approximately from 400 to 500μm whereas the non-linear analysis is 500μm. For instance, the maximum deflection sensor 0 for sections of project 1 (320 – 880 μm), project 4 (500 – 930 μm) and project 5 (300 - 800μm) were higher than project 2, project 3, project 6 and project 7 that possess ranged between 400 to 650μm. However, in this case, it is totally negligible because the variation in the subgrade modulus was lesser than the difference between the subgrade modulus and rigid foundation. [5]

The next following data below (Table 4.2 and Figure 4.8) shows the summary data of deflection ranges using BISAR 3.0 for selected zones and points in two lanes highway in each direction where the total length of this study was 15.5km. It is tested by using PRI 2100 FWD with computer program software named BISAR 3.0. Unfortunately, after one-year rehabilitations on these sections, cracks were occurred at the pavement surface. The spacing between FWD test points was 50 m with an application of 9 geophones acts as sensor whereas the point is 0, 0.30m, 0.45m, 0.60m, 0.90m, 1.20m, 1.50m, 1.80m and 2.10m. It is started with nominal impulse load 65kN over 0.30m diameter loading plate. As stated in Table 4.2, there is three zone which is S2 where the thickness of bituminous layer is same with the design thickness layer while S4 zone the thickness layer for existing bituminous layer was lower than design thickness and the total thickness also lower. Lastly, for zone S8 the thickness for the new bituminous layer is higher but the total thickness for the pavement is same.

Table 2: Summary data of deflection ranges for selected zones and points. [5]

Zone	Representative Point	Deflection (μm)								
		D_0	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
S2	100 + 400	398	317	266	223	148	96	64	44	34
S4	103 + 150	411	311	254	204	132	86	55	39	30
S8	103 + 100	871	597	457	352	187	102	59	40	30

3.2 Elastic Modulus

The data related to elastic modulus applied from Falling Weight Deflectometer (FWD) on conventional flexible pavement and testing on synthetic fiber reinforced asphalt concrete which gained from laboratory testing.

3.2.1 BISDEF

For each site where the test sections approximated to have 7 km and 105 locations that ready for investigated the flexible pavement structural performance. The test was occurred during day time with no pavement cracking or any possibility damage. As stated in the study, the asphalt density in situ within range 2400kg/m3, while the road base is around 2150 kg/m3 and the subbase was around 1850kg/m3.

Table 3: Summary if material properties and thickness of profile at site 1-7 [5]

Project/Site	Temperature during testing (°C)		Altitude	Route	Station (km)	Design Thickness (cm)		
	Air	Surface				AC	Base	Subbase
1	19.8	17.8	39.0	Dongara Rd	0 – 1.15	20	30	40
2	30.5	35.6	8.7	Barker St	0 – 1.15	20	30	40
3	18.7	25.0	15.6	Armadale Rd	0 – 1.15	20	30	40
4	29.8	37.7	22.1	Burlington St	0 – 1.15	20	30	40
5	39.8	31.4	25.5	Nicholson Rd	0 – 1.15	20	30	40
6	28.7	39.9	12.9	Star St	0 – 1.15	20	30	40
7	25.7	27.2	12.9	Orrong Rd	0 – 1.15	20	30	40

Table 4: Material properties of each layer in flexible pavement model. [5]

Pavement Layer	Modulus, (E) (GPa)	Poisson's ration (v)	Thickness (mm)	Density, ρ (kg/m^3)
Asphalt concrete	1.80	0.30	50	2400
Unbound base	1.20	0.35	150	2150
Unbound subbase	0.50	0.35	250	1850

Compacted subgrade	0.07	0.40	75	1700
Natural subgrade	0.05	0.45	Infinite	1600

Table 5: Range of effective surface layer modulus values during first iteration for site 1-7. [5]

Project/ Site	**Effective surface layer modulus (GPa)**			**Pavement temperature (ºC)**
	Minimum	Maximum	Average	
1	0.20	0.65	0.38	34.9
2	0.35	5.86	3.17	35.5
3	0.61	14.93	8.20	35.3
4	0.35	5.78	3.13	35.2
5	1.14	16.06	8.70	34.9
6	0.45	12.35	5.21	35.2
7	1.05	16.18	8.70	35.1

This study was using backcalculation method where the variation of deflection for all project are constant the deflection away from pavement load. This showed that the deflection under the load was a reflection of the modulus of the surface layer, and this pattern seemed to suggest that the lower layer controlled the response of the inflexible pavement and therefore rendered the moduli of the pavement surface layer along with the position similar. [5] The vertical deflection basins were almost similar where these indicate the way FWD interpret the data based on quality between these layers were appropriate. This showed that the developed load on the structure was capable of resisting deformation because the limits of the flexible pavement layers were designed to not be influenced by the repletion of cyclic traffic loading. [5] Project 2 and Project 3, it is shown that both base and subbase layer remains in the same trends of deflection meanwhile the subgrade layer show that the elastic moduli reading was fluctuated because need to match the farthest deflection. This shows that the FWD data, the final interpretation quality of the base and subbase modulus, would have been unacceptable due to an insignificant error on subgrade modulus, since the calculated and computed deflection basins remained approximately the same. [5] This show that the overburden and pore pressures already blocked in the horizontal stresses on the in-situ stiffness where this could lock the subgrade moduli just to match the deflection.

It is can be seen that the trend of the deflection almost same for Project 4 and 5 where this indicate that strain could develop because of unloading stress distribution. The things that need to be concerned while on testing is during the rest periods because small error might occur on the subgrade where this could determine whether the combined layer between base and subbase or the subgrade layers maybe independently affected the deflection basin causes by pavement dynamic load. [5] However, the subgrade layers typically contributed 60 per cent to 80 per cent of the overall centre deflection, so minor errors may have occurred in the moduli of the other layers. At the location for Project 6, the same moduli were repeated on the particular two layers. The average value of base layer was 0.27GPa and 0.23GPa for subgrade layer. The modulus values of these layers have been locked to allow the software to provide a stable solution, and numerous FWD test measurements and predictions have been the key to evaluating the accuracy of the modulus values. [5] The elastic modulus for Project 7, there’s a few different which is on the binder course had two sections which is damage and undamaged section. Based on the Figure 13 it is shown that the base and subgrade modulus close to each other where the elastic modulus is 0.19GPa for base layer and 0.20GPa for subgrade layer. This disparity in deflection may be due to high continuous stress at depth or lack of transfer of load to the bottom layer due to damage to the concrete asphalt layer. [5] The number of load applications are required in terms to cause 50% reduction in initial modulus that can be defined as number of cycles of failure.

3.2.2 EVERCALC 5.0 and ELMOD 6.0

The deflection in the pavement layers when different load was applied which is 6000lb, 9000lb and 12 000lb while conducting test using FWD. This study was conducted at 24 locations with 2 sections. The computer program used for FWD is Evercalc 5.0 and Elmod 6.0 (Linear elastic theory) within five layers through backcalculation method. The details of each layer can be referred by the Table 6.

Table 6: Typical ranges of elastic modulus and Poisson's ratio. [6]

Layer Type	Material Type	Thickness (inches)	Poisson's Ratio	Modulus Range (ksi)
Surface	Asphalt concrete	1.5	0.35	200 – 2500
Intermediate	Asphalt concrete	1.75	0.35	200 – 2500
Asphalt Base	Asphalt concrete	13	0.35	200 – 2500
Sub-Base	Aggregate	6	0.35	10 – 100
Subgrade	Soil	-	0.4	3 - 30

Table 7: Summary of backcalculated moduli from Evercalc 5.0 [6]

Station Number	Estimated Elastic Modulus (ksi)					RMS Error (%)
	AC Surface	**AC Intermediate**	**Asphalt Base**	**Aggregate**	**Subgrade**	
1	1153.4	269.4	544.8	3.0	86.7	1.13
2	622.9	316.1	673.3	3.0	84.8	0.80
3	270.2	382.7	1005.7	3.0	86.8	0.47
4	262.6	408.7	837.6	3.6	73.9	0.46
5	270.5	486.4	662.6	4.2	68.7	0.47
6	260.2	407.6	982.2	3.3	81.7	0.53
7	303.1	379.2	942.3	3.2	87.5	0.34
8	276.1	445.2	639.6	4.5	69.8	0.47
9	268.5	427.9	939.4	3.8	74.4	0.66
10	332.6	450.3	998.9	3.1	88.3	0.46
11	281.9	431.5	1098.2	3.2	86.3	0.58
12	240.6	500.3	905.4	3.4	86.1	0.34
13	412.3	392.6	888.9	3.5	84.8	0.38
14	388.3	456.2	1095.5	3.0	88.6	0.54
15	381.3	417.5	840.4	3.7	70	0.54
16	329.7	467.7	797.6	3.6	73.6	0.31
17	276.9	454.8	871.2	4.0	70	0.59
18	562.8	354.5	1006.2	3.1	75.9	0.23
19	246.3	386.5	1100.0	4.8	58.4	0.60
20	305.6	383.7	1099.3	5.1	52	0.35
21	224.1	559.0	897.0	4.4	48.8	0.66
22	230.2	723.9	685.9	3.0	56.3	0.90
23	210.9	582.3	789.6	3.0	61	0.64
24	314.8	429.7	903.1	3.0	64.9	0.58

The Table 7 above show the summary of backcalculated moduli from software Evercalc 5.0 where the average value for the elastic modulus for surface layer is 351ksi. Meanwhile for intermediate layer and asphalt base layer is 438ksi and 884ksi respectively. For aggregate base layer in between range 2 to 5 ksi and for subgrade is 74ksi.

3.2.2.1 ELMOD 6.0 (Linear Elastic Theory – LET)

Table 8: Summary of backcalculated moduli from Elmod 6.0 LET [6]

Station Number	Estimated Resilient Modulus (ksi)				
	AC Surface	**AC Intermediate**	**Asphalt Base**	**Aggregate**	**Subgrade**
1	719.5	327.5	407.9	4.1	65.8
2	442.3	360.3	554.1	4.5	61.2
3	238.0	504.6	615.8	4.4	61.6
4	267.7	392.2	810.3	4.4	60.2
5	327.7	413.3	718.6	4.2	64.2
6	263.1	434.8	702.1	4.1	67.4
7	283.0	396.3	718.3	4.8	61.2
8	283.0	396.3	718.3	4.8	61.2
9	314.5	391.3	829.5	4.1	67.1
10	253.2	570.0	714.2	4.2	67.4
11	289.7	421.3	929.0	4.4	64.4
12	276.5	421.3	931.4	5.0	61.4
13	447.4	382.9	773.3	4.4	66.3
14	303.2	508.5	917.2	3.9	69.2
15	340.4	508.5	649.9	3.9	64.7
16	292.6	476.2	737.8	4.4	63.0
17	264.6	435.9	894.3	4.2	63.7
18	359.1	478.2	741.2	4.2	62.2
19	225.3	405.7	1175.4	4.2	57.9
20	320.1	365.6	1039.9	5.6	49
21	251.9	452.3	1335.7	3.2	54.2
22	247.6	587.3	792.3	3.3	51.7
23	219.9	548.6	784.4	3.5	52.3
24	239.2	459.9	955.9	3.4	56.5

The Table 8 above show the summary of backcalculated moduli from software Elmod 6.0 (Linear Elastic Theory- LET) where the average value for the elastic modulus for surface layer is 311ksi. Meanwhile for intermediate layer and asphalt base layer is 443ksi and 810ksi respectively. For aggregate base layer in between range 2 to 5 ksi same as Evercalc 5.0 data and for subgrade is 61ksi.

3.2.3 Elastic Modulus in Synthetic Fiber

The data regarding elastic modulus in synthetic fiber where the reviewed data gained from laboratory testing.

3.2.3.1 Polypropylene and Aramid Fiber

Table 9: Elastic Modulus at 250C (770F) results for HMA with and without fibers. [7]

	Average Resilient Modulus, MPa (ksi)	Standard Deviation
HMA control	8392	829 (1 2 0)
HMA with Fibers	9651	669 (2 0 3)

Table 9 shows average results of resilient modulus where the conditions of specimens at 250C where HMA with fibers show 15% higher than HMA control which is without fiber contained. This indicate the stiffness increases when fibers were added into HMA. From these consequences, lead the asphalt pavements could withstand towards rutting. This can be referred to Table 9 where the reading of moduli for HMA mixed with fibers had 30% higher rather than control HMA at high and low temperatures. The fibres could contribute to asphalt pavements at higher temperatures to better resist rutting or permanent deformation. [6]

3.2.3.2 Polyolefin-Glass Fiber

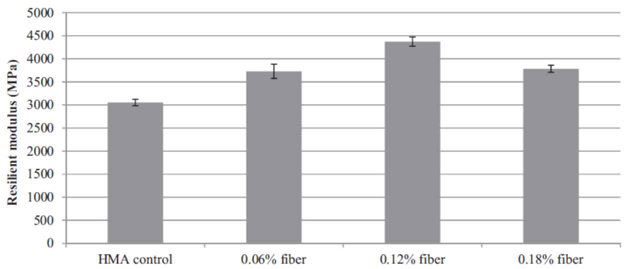

Figure 4: The resilient modulus test results of asphalt mixtures containing different percentages of polyolefin-glass fiber. [8]

From the figure 5 above it is shows the different percentage of fiber contained in asphalt mixtures where almost 50% increases the resilient modulus when 0.12% polyolefin-glass fiber were added. Unfortunately, not all mixture that added more fibers will increase the resilient modulus as this occurred on 0.18% of fiber resulted substantial decrease where this could cause agglomeration of glass fiber during production. The three-dimensional dispersion of the glass fibres in the mixture also affected the deformation resistance of the mixtures and subsequently its resilient modulus, particularly when subjected to indirect tensile loading. [8]

4. Conclusion

From these testing a few types of result can be achieved such as vertical deflection and elastic modulus. A few considerations need to take care during conducting these testing especially on temperature as the bitumen material affected by temperature variation but does change in its characteristics. So, the temperature effect on the FWD especially during measured the deflections. Subgrade and aggregate layer easily effected by moisture condition, in other terms correction factors are related to environment and material specified. These can be proved the suitability field condition through the deflection data and a set of layer moduli for the pavement if the results are reasonable. From these testing using FWD it is also showed that the layer thickness of pavement and the repetition load give a significant impact on the permanent deformation of flexible pavements as these parameters allows the estimation of pavement remaining live. With the increasing of traffic load, the focus concerned more on the material additives inside the asphalt mixture in terms to improve the pavement design, life span of pavement and resist from any defects of pavement. The fiber reinforced asphalt mixture were compared with normal asphalt mixture which is without fiber (control mix). The combination more than one type of synthetic fiber could help increasing the performance of asphalt mixture compared than control mix. With the proper amount of fiber could enhance the performance asphalt mixture but if the excessive amount of additive fiber could causes wastage of cost as mechanical properties of each fiber will give a different result of performance impact on the asphalt mixture.

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