LOAD PULSE WIDTH AND DEFLECTION ANALYSIS USING HWD AND MDD DATA AT NATIONAL AIRPORT PAVEMENT TEST FACILITY

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ABSTRACT

Heavy Weight Deflectometer (HWD) tests on flexible pavement at different loading levels of 12,000, 24,000, and 36,000 lbf were performed at the Federal Aviation Administration (FAA)'s National Airport Pavement Test Facility (NATPF) located in Atlantic City, New Jersey. The FAA equipment used for the testing was a KUAB Model 240 HWD configured with a 12 inch diameter plate. Testing was performed directly on two different Multi-Depth Deflectometers (MDD) embedded in the flexible pavement to validate the HWD data by comparing to the measured MDD data. Based on the data analysis, three different methods of load pulse measurements including the method used for FAA's F/HWD Roundup are presented and discussed in this paper. In addition to MDD monitored load pulse widths at different traffic speed levels using the NAPTF full scale test vehicle are presented. From an examination of the MDD responses accuracy before and after the load drops, potential errors were detected caused by the HWD weight and the towing vehicle weight. The deflections are included in this paper. Temperature effects on flexible pavement response measurements were analyzed using the collected HWD data from the flexible pavements at different traffic numbers. Deflection basin area, maximum deflection, and basin shape factor were computed for the analysis. The results showed close correlations between the three parameters and pavement temperature.

INTRODUCTION

One of the simple and convenient methods to assess pavement structural integrity is measuring deflection responses to the applied load on the pavement surface. It has been continuously improved starting from the Benkelman Beam method measuring the maximum pavement deflection of static wheel loads using dual truck tires to the Falling Weight Deflectometer (FWD) delivering a transient impulse load to the pavement surface. The Advisory Circular (AC) 150/5370-11B describes three primary parameters to be considered that affect HWD responses [1]. In this paper, the parameters referenced in the AC are reviewed using HWD and MDD data collected at the NAPTF located at the William J. Hughes Technical Center near Atlantic City, New Jersey. The FAA owned HWD dropped loads directly on three different MDDs embedded in flexible pavement to validate the HWD data by comparing to the measured MDD data. MDD monitored pavement responses to the NAPTF full-scale test vehicle loading are discussed to compare with the HWD created pulse widths. The pavement responses to the HWD loads, pulse width, and pavement temperature are investigated to find appropriate load level for airfield pavements, to propose a pulse width computation method, and to investigate temperature dependency of the HWD results, respectively. Three different methodologies to compute the pulse width are introduced and proposed using the data from the HWD and MDD. HWD created pavement deflection basin changes with different pavement surface temperatures are monitored as well. The results, analysis, and findings are presented.

TEST CONDITION

The FAA research team operated the HWD on top of the embedded MDD in Construction Cycle 5 (CC5) flexible pavement test pavement items. Structures and materials used for the pavement construction, HWD test conditions, and MDD locations will be described in this paper.

Test Pavement

The CC5 was composed of 5 inches of Hot Mix Asphalt (HMA) surface layer (P-401), 8 inches of base course (P-209), 34 and 38 inches of granular materials (P-154) constructed on a CH clay subgrade known as DuPont clay subgrade within the NAPTF. The testing area was configured as shown in Figure 1. Figure 1 shows the CC5 pavement structures and corresponding MDD locations embedded at stations 210 and 260 at 16 feet offset from the centerline. The MDD sensors numbered 10 and 12 are located at the bottom of the P-209 crushed aggregate base, at top and middle of 34 and 38 inches thick P-154 granular base, and top of DuPont clay subgrade. The upper two feet of the subgrade, for all the sections, were reprocessed and compacted in 6 inches lifts using clean material from the excavation.

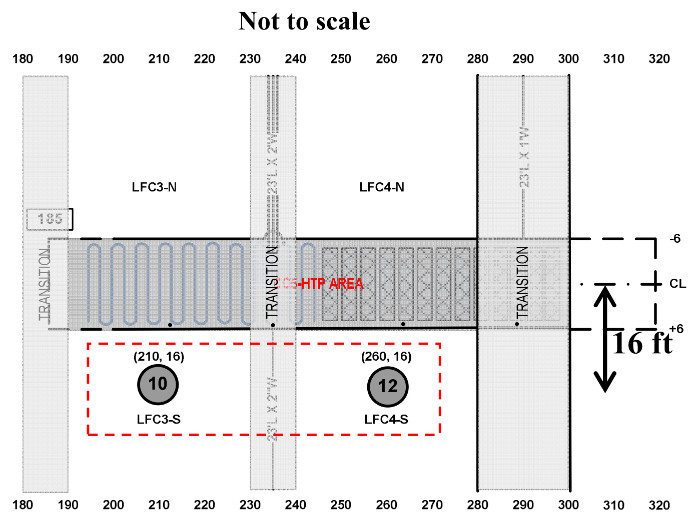
Falling Weight Deflectometer

The FAA owned KUAB Model 240 HWD configured with a 12 inch diameter segmented load plate to ensure an uniform pressure distribution over the full area of the plate was used to drop loads directly on the embedded MDD in the CC5 flexible pavement. Three loading levels in the sequence of 36,000 lbs (seating), 12,000 lbs, 24,000 lbs, and 36,000 lbs were used in the tests, and the pavement surface temperatures ranging between 47 and 86°F. The temperatures are measured by the HWD temperature sensor. The test conditions follow the AC 150/5370-11B describing load amounts, load modes, and pavement temperatures as primary parameters to be considered to affect HWD responses.

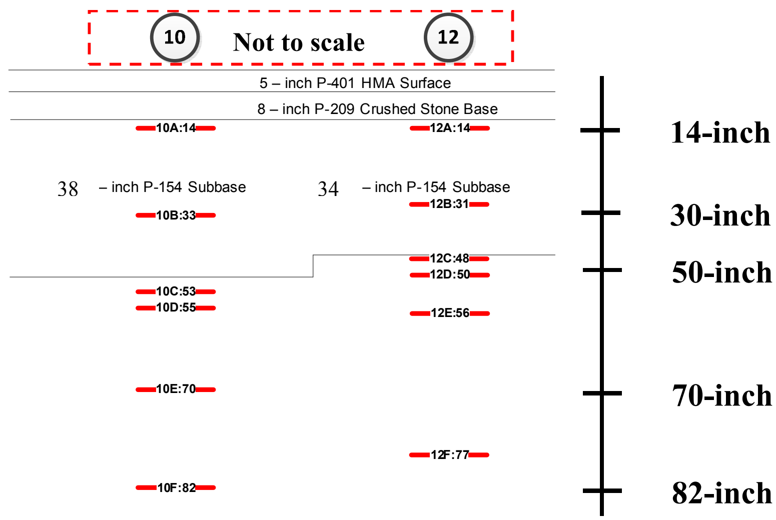
The transient response of the pavement system to an impact loading is recorded by the KUAB HWD system. Typical response through the KUAB double buffer system is saved in time history data showing deflection and load traces to compute pulse width. The response monitored at seven geophones and recorded load amount with HWD measured pavement surface temperatures were analyzed. The load amount read directly from the HWD system was used for pulse width analysis. The maximum deflection from geophone D0 (0-offset) at each loading was used for creating deflection basin.

Multi-Depth Deflectometers

MDD sensors were embedded in all of the twelve test items in the CC5. The MDD sensors are located in the middle of each test item and zero-track wander location to monitor pavement responses to different traffic conditions, pavement structures, and materials. Detailed information for each test item is provided at the FAA website [2]. Two MDD sensors were selected from the South LFC3-S and LFC4-S test items. Because CC5 traffic tests were conducted started from all the North test items, both items, South LFC3-S and LFC4-S, remain nontrafficked when the HWD tests were conducted directly on the MDD. LFC3-S and LFC4-S have 5 inches P-401 on 8 inches P-209 except subbase thickness of 38 and 34 inches, respectively, as shown in Figure 1. Six deflectometers were linked to each MDD to record responses at the subbase layer and subgrade. The deflectometer located at 14, 31, and 33 inches were installed in the P-154 subbase. The 48, 50, 53, 55, 56, 70, 77, and 82 inches were installed in the subgrade, DuPont clay. The locations are depicted in Figure 1.



(a)



(b)

Figure 1. CC5 Pavement Structures and Corresponding MDD Locations in (a) Plan View and (b) Pavement Cross Section.

LOAD MAGNITUDE

A 36,000 lbs target load was applied by HWD following the load sequences of 36,000 (seating), 12,000, and 24,000 lbs. Influenced pavement depths generated by each HWD load amount were computed based on the MDD responses located in the test items LFC3-S and LFC4-S. Figure 2 shows maximum deflections measured by MDD 12 in LFC4-S when the four different load magnitudes were dropped. In the figure, the dotted black line at 48 inches depth represents the line between pavement layers and subgrade. Significant deflection changes are noted with increasing depth except the deflectometer located at 56 inches below the surface, as marked in the figure, with 12,000 and 24,000 lbs load magnitudes. Using the lower amount of

HWD loading, the sensitivities of the pavement deflections to the pavement depths are negligible below the top of subgrades. Similar patterns were measured in MDD 10 in LFC3-S as MDD 12 as shown in Figure 2. The 36,000 lbs load can be considered a reasonable target HWD load to obtain subgrade characteristics for further HWD data analysis such as backcalculation.

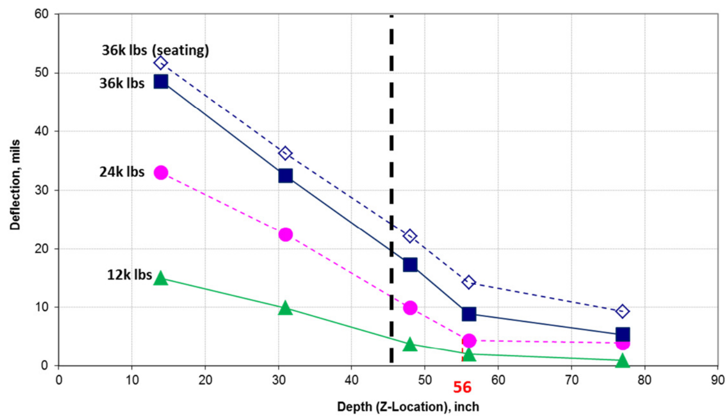


Figure 2. MDD 12 Responses to Four Levels of HWD Load Magnitudes.

LOAD PULSE WIDTH

In forced vibration there is a quantity related to damping that is a measure of sharpness of resonance. In general three conditions of damping in a system response curve would be under damped, critical damped, and over damped. Because all the HWD systems are operated with installed buffers, applying the measure of sharpness of resonance to the HWD loading system, the measured forced vibration will be under damped conditions. Each manufacturer generates typical response curves with peak overshoot, oscillation period, tolerance band, response time, setting time, and rise time. For example, higher rise time and lower tolerance band are typical in JILS and CarlBro HWD systems, respectively. Figure 3 shows an example of load and deflection changes recorded by the FAA owned KUAB HWD. The 36,000 lbs HWD load generated convex shapes are shown in Figure 3.

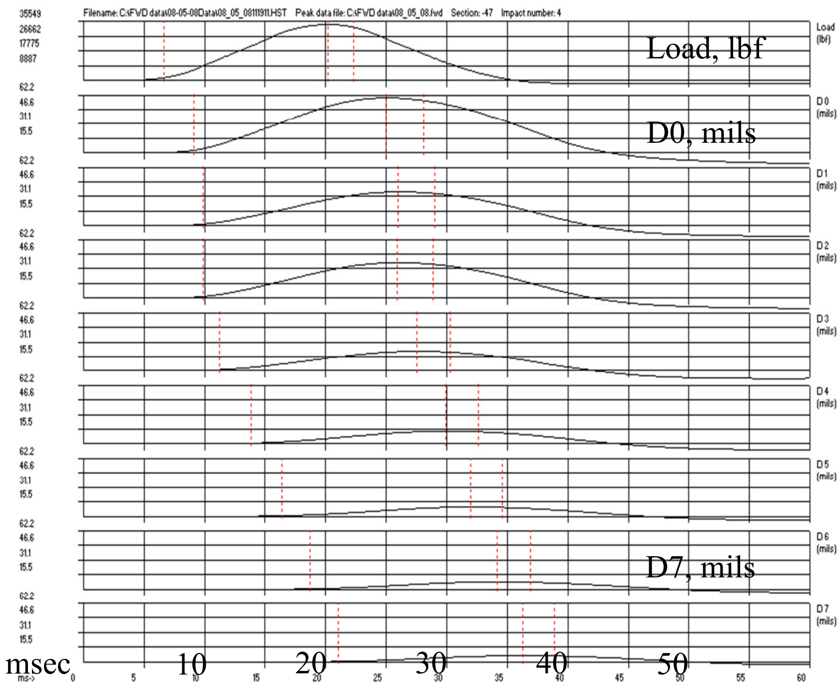


Figure 3. Example of 36,000 lbs HWD Load Generated Convex Shapes at Each Geophone.

Based on time domain plots in milliseconds (msec) and the KUAB load shapes, three approaches to compute the load pulse width were examined noted below.

- Pulse Time (Tr): 90 percent of the time from zero slope to peak load on each side of peak value.
- Rise Time (Tm): Two times of elapsed time from zero slope to peak load.
- Transient (Tt): Elapsed time between the two steady states (zero slopes).

Figures 4, 5, and 6 depict the three approaches for load pulse width computations. The first method shown in Figure 4 takes 90 percent of the peak load value for both sides of the pulse (Tr). The pulse widths from before and after peak load were computed separately and were added later. This method computes accurate pulse width in non-symmetric shapes recorded during an individual load drop. This method was adopted for the FAA's F/HWD Roundup [3]. Figure 5 shows the second method using rise time (Tm). It computes an elapsed time from the state before an impact load to peak load. Double the elapsed time gives pulse width in the method. In other words, the pulse width for this method is defined as two times the computed elapsed time from the start of a data point responding to impact load to maximum data point recorded by the HWD. In perfect symmetric bell shapes, equal pulse width will be made by multiplying two (2) of rise time based on either the first or the second half. It is typical to have longer time elapse in the second half in "under damped" conditions, even though it is observed that the shape shows close to symmetry in this study. This method is used for pulse width computation in the KUAB manual. The third method is Transient (Tt) as shown in Figure 6. It measures elapsed time between the two steady states, before and after placing load. This method takes 100 percent of elapsed time from the start to the end data points responding to the impact load. The method is basically derived from the first method which considers 90 percent of the peak value.

The first method would provide a reasonable computation method including both sides of load generated pulse shape and considering direct pavement responses after inflection point.

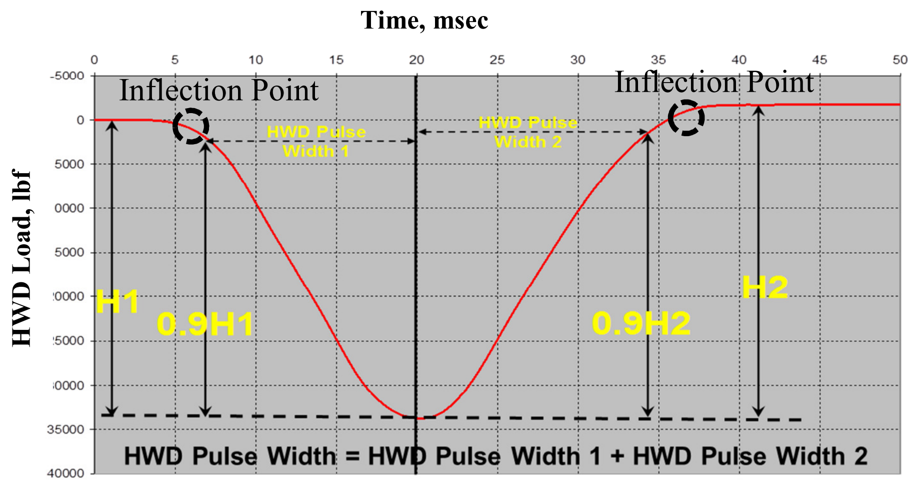


Figure 4. Pulse Time (Tr) Method to Compute HWD Pulse Width Using 90 Percent of the Time from Zero Slope to Peak Load.

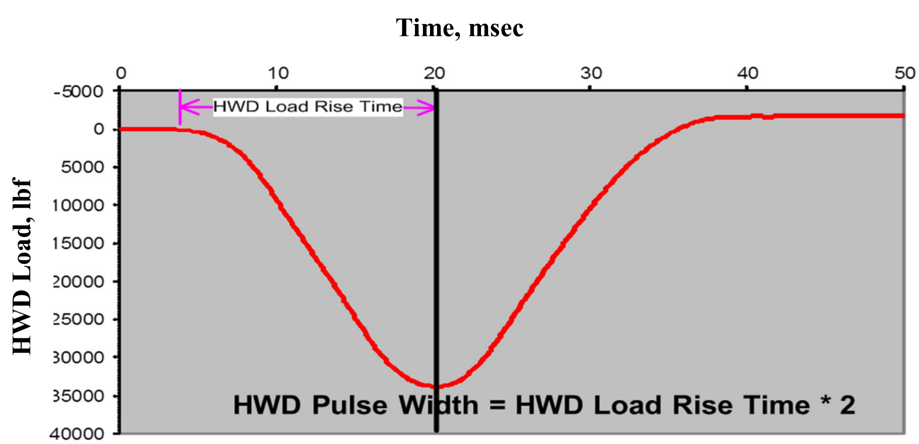


Figure 5. Rise Time (Tm) Method to Compute HWD Pulse Width Using Two Times of Elapsed Time from Zero Slope to Peak Load.

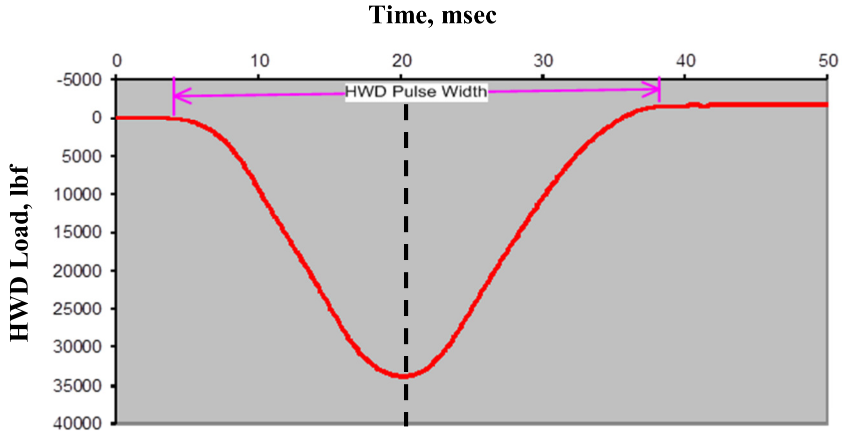


Figure 6. Transient (Tt) Method to Compute HWD Pulse Width Using Elapsed Time Between the Two Steady States, Before and After Load Placement.

The load pulse width was also monitored by MDD at the same time of HWD system when the HWD load was dropped directly on the MDD in the asphalt surface. The computed pulse widths by the three proposed methods are summarized in Table 1 using the two different data collection systems, MDD and HWD. The MDD 10 responded deflections are plotted with load variations recorded by HWD system in Figure 7. The MDD captures the impact loading in real time with little shifting. Note that the MDD deflectometers are embedded down to 7 feet below the pavement surface with three layers including unbounded materials. Based on the three methods in the computations, pulse widths from the MDD presented were higher pulse width by approximately 6 to 15 percent except Rise Time (Tm) in MDD 10 showing 1 percent less width.

Table 1. Computed Pulse Widths from The Proposed Three Methods At 36,000 lbs load level.

Method	Sensor Type	HWD, msec (average)	MDD, msec (average)
Pulse Time (Tr)	MDD 10	39.75	45.00
	MDD 12	40.05	46.25
Rise Time (Tm)	MDD 10	40.50	40.00
	MDD 12	40.30	45.00
Transient Time (Tr)	MDD 10	39.60	43.98
	MDD 12	40.45	43.13

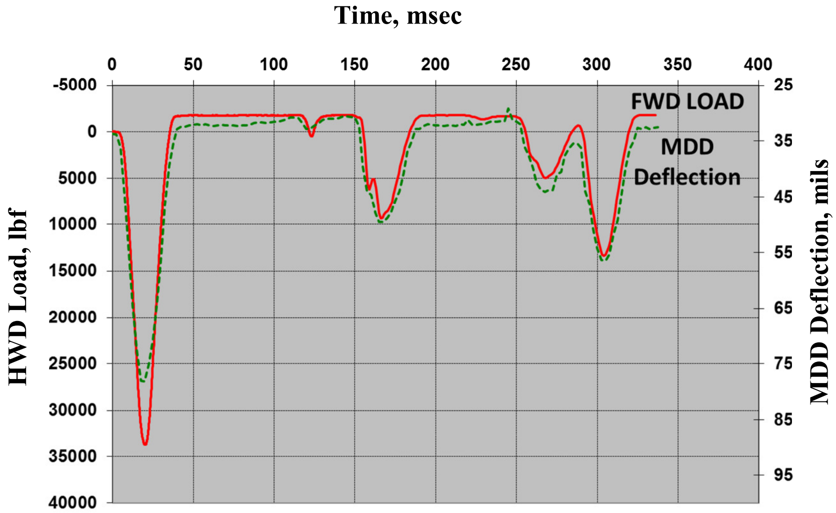


Figure 7. MDD 10 Responded Deflections and HWD Recorded Load Variations.

Dynamic traffic loading using the National Airport Pavement Test Vehicle (NAPTV) was applied to monitor pulse width changes in the MDD readings. Since the MDD 10 and 12 were not trafficked at the time of HWD tests, another MDD embedded in a test item with traffic records was selected for sensitivities of dynamic loading speeds. The test speeds were varied at 0.25, 0.5, 1.0, 2.5, and 5.0 mph with 65,000 lbs wheel loading and 4-wheel gear configurations, 54 and 57 inches between tires and modules, respectively, at inflated tire pressures of 234 psi. The pulse width changes are shown in Figure 8. The embedded deflectometers were located at the top and bottom of P-154 and in the subgrade. In Figure 8, they are labeled A, B, C, D, E, and F corresponding to 14 inches (P-154), 47 inches (P-154), 50 inches (subgrade), 56 inches (subgrade), 65 inches (subgrade), and 77 inches (subgrade) from the pavement surface. As shown in the figure an inflection point is formed slightly below the 1 mph test speed corresponding to 18 msec pulse width followed by drastic increases for 0.5 and 0.25 mph speeds. The pulse width range from 20 to 60 msec in AC 150/5370-11B corresponds to speeds below 1 mph which could be considered as taxiway speed in the field.

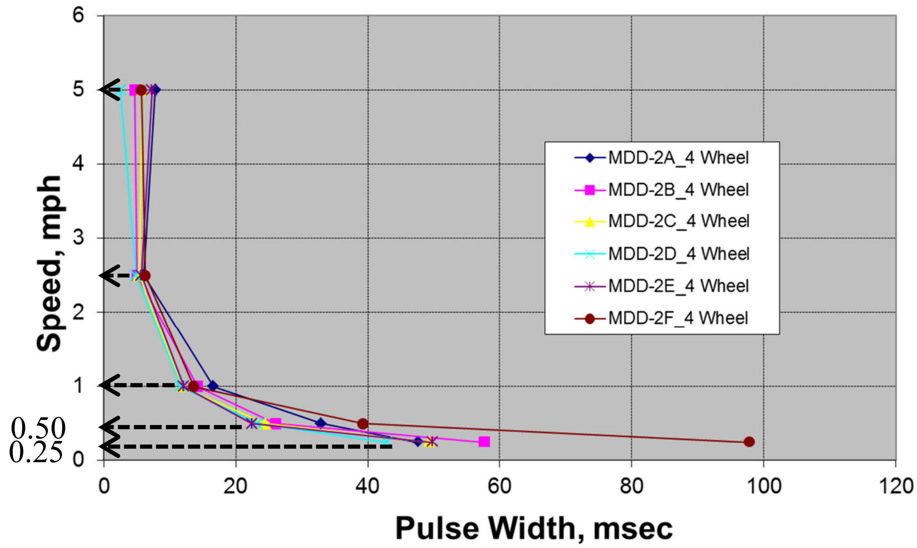


Figure 8. Pulse Width Changes in MDD with Dynamic Loading Speeds.

PAVEMENT TEMPERATURE

Following AC 150/5370-11B, HWD tests were performed in moderate pavement temperatures between 47 and 86°F. In the temperature range, HWD tests were conducted at 47, 70, 78, and 86°F, maximum deflections at geophone D0 were changed at the ratio of 0.15 (from 47 to 70°F), 0.57(from 70 to 78°F), and 0.75(from 78 to 86°F) mils/°F. At the geophone D1 which is 12 inches away from the load drop location, deflection change ratios were 0.05(from 47 to 70°F), 0.33(from 70 to 78°F), and 0.29 (from 78 to 86°F) mils/°F. They are summarized in Table 2. As shown in the table, D0 and D1 are more sensitive to pavement temperature changes above 70°F than below. Assuming the HMA layer (P-401) is only susceptible to temperature as a viscoelastic materials depending on temperatures and time, the two geophones (D0 and D1) mostly correlated to pavement surface layer were selected for analysis of HWD deflection changes at different pavement temperatures.

Table 2. HWD Deflection Changes with Increasing Pavement Surface Temperatures.

Pavement Surface Temperature, °F	D0, mils	D1, mils	D0 Increase Ratio, mils/°F	D1 Increase Ratio, mils/°F
47	43.34	32.74	NA	NA
70	46.82	33.99	0.15	0.05
78	51.40	36.65	0.57	0.33
86	57.37	38.96	0.75	0.29

During the traffic testing on the CC5 test items, HWD testing was conducted and the deflections were monitored within traffic zones with increasing traffic pass number. The maximum deflections at the 0 offset geophone are compared with P-401 surface temperatures in Figure 9. With increasing CC5 traffic test numbers, the HWD measured maximum deflections and also pavement temperatures were decreasing during the traffic testing. The maximum deflection at 0 offset which is directly related to the surface layer characteristics is strongly depending on the surface layer temperatures. Maximum deflection is increased and decreased at 8,500 passes before reaching 10,000 as temperature does at 8,500 passes. Also, similar temperature dependent patterns were found at the CC5 items without any traffic loadings, computed basin area, and area basin shape factor (ABF) as shown in Equation (1), which proves the temperature dependency of HWD results. The ABF is a result of numerically integrating a normalized deflection basin and relates to the ratio of pavement stiffness to subgrade stiffness [4].

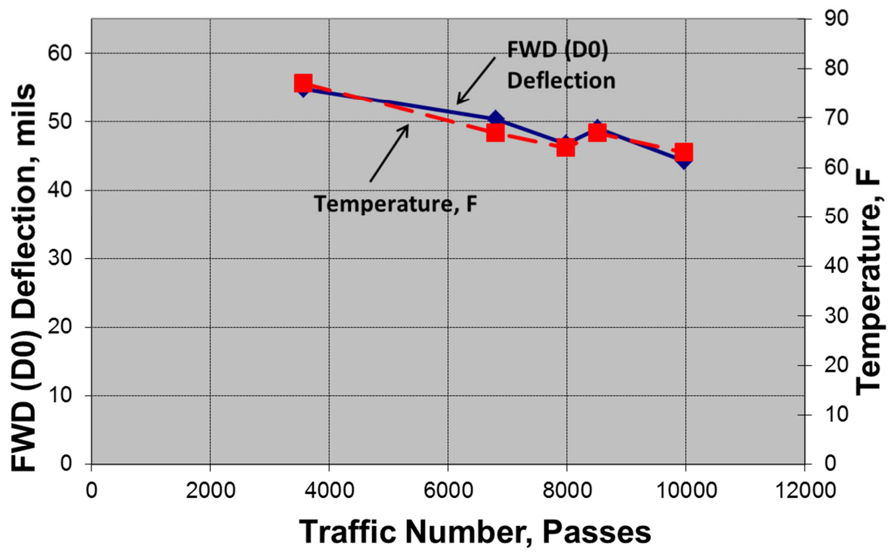


Figure 9. HWD Deflection Changes and Pavement Surface Temperatures with Increasing Traffic Pass Numbers.

$$ABF = \frac{6 \cdot \left[D_0 + 2\sum_{i=1}^{n-1} D_i + D_n \right]}{D_0} \tag{1}$$

where,

D_0 = Geophone located at 0 offset,

D_i = Geophone location at i=1, 2, …, n,

ADDITIONAL PAVEMENT DEFLECTION

Accuracy of MDD 10 and 12 responses were evaluated at the time of before and after the HWD load drops. The examination shows significant pre-loading deflections caused by the HWD device and towing vehicle weight. The amount of unexpected loading could be considered as potential errors, and needs to be included for further data analysis after HWD deflection data was collected. The accumulated maximum deflections monitored by MDD 10 before dropping target load, 36,000 lbs, was 34 mils as shown in Figure 10. The figure shows all the deflections collected from all six deflectometers in the MDD. Knowing maximum deflections during the full scale traffic testing recorded between 45 and 55 mils in Figure 9, the pre-loading deflection by the HWD device and towing vehicle already deformed 62 to 76 percent of the maximum deflections even before loading drops.

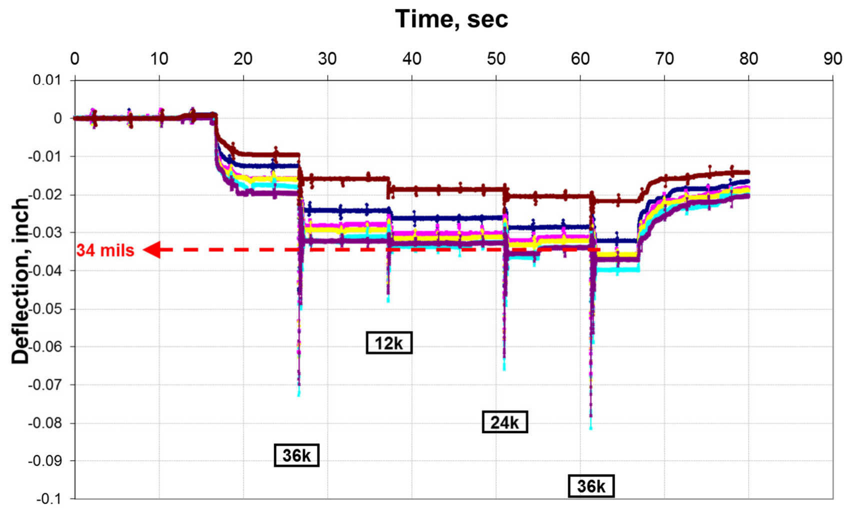


Figure 10. MDD 10 Monitored Deflections During HWD Testing On Nontrafficked HMA Pavement.

CONCLUSION

The FAA's NATPF performed HWD tests on flexible pavement at loading levels of 12,000, 24,000, and 36,000 lbs. Testing was performed directly on two MDD embedded in the flexible pavements to validate the HWD data by comparing to the measured MDD data.

MDD responses to the measured HWD impact loading shows similar patterns as HWD system recorded load changes. Based on the data analysis, three different methods of load pulse measurements including the method used for FAA's F/HWD Roundup were proposed. They are Pulse Time (Tr), Rise Time (Tm), and (Tt). The Pulse Time (Tr) provides the most reasonable computation method including both sides of load generated pulse shape. The method would be adopted to compute generated pulse widths by all F/HWD devices, even though each pulse shape is different.

Temperature susceptibility and dynamic loading speed sensitivity were also investigated. Based on the collected data during the CC5 full-scale traffic testing, strong correlations between pavement surface temperatures with HWD deflections were identified. MDD monitored load pulse widths at full-scale traffic speed levels show more sensitivity to the pulse width at below 1 mph dynamic loading speed.

In addition, potential MDD measurement errors (difficulties) were detected caused by the HWD and the towing vehicle weights. The pre-loading (static) deformation from the weight of the test vehicle was found to be more than 60 percent of the total deflections generated by the 36,000 dynamic superimposed loading.

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