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October 28, 2004

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Subject: **Comparison Study of the JILS Model 20T and Dynatest Model 8002 Falling Weight Deflectometers.** ARA Project No. 16214

Dear Mr. Sanati:

Applied Research Associates, Inc. (ARA), ERES Consultants Division, is pleased to deliver to Foundation Mechanics, Inc., our findings in the comparison study between the JILS Model 20 T and Dynatest Model 8002 Falling Weight Deflectometers (FWDs). ERES conducted side-by-side testing on three different pavement structures for comparison of load pulses, deflection basins, and backcalculated subgrade moduli. In addition, equipment characteristics of both machines are summarized.

It has been a pleasure providing these services to Foundation Mechanics, and we look forward to having the opportunity to work together in the future. If you have any questions or comments regarding this report, please do not hesitate to contact us.

Sincerely,

Douglas A. Steele, P.E.	Michael J. Harrell, P.E.
Senior Engineer	Staff Engineer

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Comparison Study of the JILS Model 20T and Dynatest Model 8002 Falling Weight Deflectometers.

October 28, 2004

BACKGROUND

Falling Weight Deflectometers (FWDs) are the most common devices used for the nondestructive structural evaluation of pavements in the U.S. and throughout the world. ERES Consultants, a division of Applied Research Associates (ARA), Inc., has provided FWD testing services to private and public clients for over 10 years. The first deflectometer we purchased was a Dynatest Model 8081 Heavy Weight Deflectometer (HWD), in 1993. It was followed by the acquisition of a second Dynatest HWD and three Dynatest Model 8002 FWDs. While ARA has been satisfied with the data quality, service, and operation of our fleet of Dynatests, when the time came to acquire additional equipment, we desired to give equal consideration to all manufacturers' equipment, with an emphasis on equipment innovations that could benefit our testing operations.

Candidate Devices

Through their participation in FWD User Group meetings and information available on their website, Foundation Mechanics, Inc. (FMI) and their truck-mounted JILS FWD Model 20T became an item of interest. As the time approached for ARA to purchase an additional deflectometer for its fleet, we made a precursory screening of all FWD models currently, or that will eventually be made, available for purchase in the U.S. The FWD manufacturers considered included Dynatest, Foundation Mechanics, Carl Bro, and KUAB.

The concept of an FWD mounted in a vehicle, as opposed to a trailer-mounted FWD with a dedicated tow vehicle, quickly caught our interest. The operational advantages, such as maneuverability and decreased maintenance, were obvious and we decided to focus our search only on vehicle-mounted FWDs that either existed, or could be made available, in the U.S. This shortened the list of candidates to Foundation Mechanics, Carl Bro, and KUAB. At the time of ARA's FWD search (early 2003), Dynatest did not manufacture a vehicle-mounted FWD, or have plans to produce one.

Carl Bro offers a van-mounted FWD; however, they do not have a sales and service presence in the U.S., and their only equipment sold in North America consisted of a trailer-mounted FWD in Quebec. Due to the unavailability of a sample vehicle-mounted device, and concerns over future service and support due to the lack of an established North American presence, ARA eliminated the Carl Bro device from consideration. The KUAB version of a vehicle-mounted FWD utilizes a delivery-truck type vehicle that encloses the FWD. Although this system has been sold overseas, a sample unit does not currently exist in North America, which would have allowed a thorough evaluation of its operation and quality of data. In addition, ARA found the choice of vehicle platforms to be bulky and potentially high on maintenance. Therefore, it was also eliminated from further consideration.

Comprehensive Evaluation

ARA evaluated the JILS FWD through review of existing FMI marketing information, a field comparison of our Dynatest FWD and HWD data with a trailer-mounted JILS FWD owned by the Iowa DOT, and an on-site visit to a JILS truck-mounted FWD owned by the Arizona DOT. Our evaluation criteria consisted of the following:

- Quality of load and deflection data, including past calibration history
- Maneuverability and ease of operation, including field program and data output file format
- Added features (e.g., temperature sensors, distance measuring instrument [DMI], and video camera system)
- Maintenance history and customer satisfaction with support and service
- Number of units and references for units with similar characteristics in operation in North America
- Cost and delivery time

The JILS FWD received high marks in all categories. ARA was particularly impressed with the shape and repeatability of the JILS load pulse, its ability to pass the SHRP calibration protocol, its simplicity of design (i.e., minimal moving parts, short cable runs, few switches, and straightforward operational software), and its FWD powering system, consisting of a gas-engine driven hydraulic system. At the time of our evaluation, JILS had six vehicle-mounted FWDs in service in the U.S., two of which had been in use for 6 years. The three JILS customers queried as part of this evaluation provided positive feedback in terms of maintenance and technical support. In terms of initial purchase cost, the base cost provided by FMI made it comparable to the equivalent of a traditional tow vehicle/trailer-mounted FWD system, as well as other manufacturers' vehicle-mounted devices.

Based on our evaluation, ARA placed an order for a new JILS Model 20T FWD in May 2003. The device was delivered to ARA's office in Champaign, Illinois, in October 2003. To provide an independent comparison of JILS and Dynatest FWD load and deflection data, FMI commissioned ARA to perform side-by-side testing of our new JILS FWD with one of our existing Dynatest FWDs. This report summarizes the results of that comparison.

EQUIPMENT DESCRIPTIONS

The following paragraphs describe the ARA-owned JILS and Dynatest FWDs used in this comparison.

JILS Model 20T (Serial No. 104)

The JILS Model 20T used in this comparison is mounted in the bed of a Ford E350 dual-tire pickup truck with a Reading utility box installed on the truck's chassis. The Ford truck is a 2003 model year, 10-cylinder, gas engine Super Cab. As seen in figures 1 and 2, the load-generating portion of the FWD is installed in the bed of the truck, just to the rear of the rear axle. The sensor bar extends rearward of the load plate and folds upward during transport between test points.

The JILS FWD is capable of testing with nine geophones, although only seven were used in this demonstration. The sensors can be moved to fixed locations along the bar, ranging from 0 to 60 in to the rear of the load plate and 12 in to the front. The geophones are mounted on tripods placed on the sensor bar and held in place by a single large spring each. The 12-in-diameter load plate is a single piece. Unlike the Dynatest FWD, which utilizes a swivel to allow the load plate to rotate slightly with respect to the loading column, the JILS FWD utilizes two adjustable air bags located at the top of the loading frame

Figure 1. JILS Model 20T FWD with the sensor bar in the transport position.

Figure 2. JILS Model 20T FWD with sensor bar in the testing position.

to allow the entire loading column to rotate, ensuring that the load is always dropped perpendicular to the road surface. The load range can be varied from approximately 3,000 to 20,000 lbf.

The powering system of the JILS is significantly different from the Dynatest. It consists of a 16-hp Kohler gas engine that directly drives the pump of the hydraulic system that controls the machines movements (i.e., raise/lowering of the side cylinders and main cylinder). The JILS can complete a 3-drop sequence of a single drop each at loads of 9, 12, and 16 kips in approximately 24 seconds. The method of determining drop heights also differs from the Dynatest, in that the JILS controls drop height based on a force vs. lift time relationship developed at the start of the testing day. Based on the desired load levels, the JILS software determines the length of time to lift the mass to achieve the desired loads.

The JILS FWD is operated by means of a laptop inside the cab. The data collection program is Windows-based and allows the operator to store either the complete time history data, or just peak loads and deflections. There is not a separate system processor module, as analog to digital conversions are done on a PCMCIA data acquisition card. The JILS offers peripheral devices such as air and pavement surface thermometers, a distance measuring instrument (DMI), geographic positioning system (GPS), and a video and monitor system to allow viewing of the load plate during testing. It has a tower for performing relative calibration of the geophones and both the load cell and deflection transducers are compatible with the SHRP calibration protocol.

Dynatest Model 8002 (Serial No. 053)

The Dynatest FWD used for comparison testing is a typical Dynatest Model 8002, in that it is a trailer-mounted FWD that measures deflection with geophones placed on a sensor bar forward of the load plate. The number and spacing of sensors is variable; for this testing, seven sensors were used. The FWD can be towed by any suitable vehicle, and in our case, we have modified the FWD powering system through use of a gas generator mounted on the trailer frame. The generator runs a battery charger that charges two maintenance-free car batteries, which in turn run the FWD’s electric motor and hydraulic pump. The Dynatest varies force through use of different weight/buffer configurations and can produce loads ranging from approximately 3,000 to 27,000 lbf. In this case, a single piece 11.8-in-diameter load plate was used. The Dynatest FWD used in this comparison performed a 3-drop sequence of a single drop each at 9, 12, and 16 kips in approximately 35 seconds. A picture of the Dynatest FWD testing is shown in figure 3.

The Dynatest offers the same peripherals as the JILS, such as air and pavement surface thermometers, onboard DMI, GPS, and a video camera system for load plate monitoring. At the time of this comparison, data acquisition (including analog to digital conversion) was performed in a stand-alone system processor and transferred to a laptop computer. Dynatest offers a Windows-based data collection program, as well as proprietary data analysis and design software. The data collection software allows for storing of either time history or peak data. The FWD comes with a tower for performing relative calibration and is compatible with the SHRP protocols for deflection transducer and load cell calibration.

Figure 3. Dynatest Model 8002 FWD with the load plate in the testing position.

Comparison of Features and Specifications

Table 1 summarizes many of the key design and performance features of the JILS Model 20T and Dynatest Model 8002 FWDs. In several cases, the features of the devices reflect typical machine capabilities, and not the specific devices used for this comparison. For fairness in comparison, we have tried to list typical device capabilities, and not the exact specifications of the machines tested, as these may be affected by age.

Table 1. Comparison of features.

Feature	JILS Model 20T	Dynatest Model 8002
Number and type of deflection sensors	9 geophones available (7 used in this study)	9 geophones available (7 used in this study)
Orientation of main sensor bar	Rear of load plate	Forward of load plate
Additional sensors available	12-in forward of load plate	12-in left, right, and behind load plated
Load column tilting mechanism	Air bags	Load plate swivel
Load plate type and diameter	12-in solid plate	11.8-in solid (split plate and 17.7-in solid plates are available as options)
Measured cycle duration (3-drop sequence)	24 sec	35 sec
Powering method	18 HP gas engine	160 amp alternator and ½ HP DC motor
Air and pavement surface temperature sensors	Yes	Yes
Distance measuring instrument	Yes	Yes
Video camera monitoring system	Yes	Yes
GPS referencing	Yes	Yes
Signal processing	DAQ card installed in laptop's PCMCIA port	9000 system processor module (models prior to 2004)
Field program	Windows-based (V.XX)	DOS-based (V.25) Windows-based is available (FWDWin)
Data file formats	ASCII Text (standard)	ASCII Text (V.10 – V.25, FWDWin) MS Access database (FWDWin)
Ability to store peaks and time history data	Yes	Yes
Relative calibration procedure available	Yes	Yes
Compatible with SHRP calibration centers	Yes	Yes

DATA COLLECTION

ARA performed side-by-side testing on November 12-13, 2003. To simulate multiple real-world applications, we tested three different roads of varying pavement types and thickness in Champaign County, Illinois. The three sites consisted were:

- 6-in asphalt concrete (AC) pavement on Staley Road
- Chip seal pavement on Rising Road
- 8-in portland cement concrete (PCC) pavement on Mullikin Drive

We tested 11 points at 50-ft intervals at each site, and the test locations were painted to ensure that each FWD positioned its load plate at the same location. On the two flexible pavement sections, we tested in the outer wheel path, while we tested at slab centers on the PCC road. At each test point, a seating drop was made, followed by a three-drop sequence consisting of a single drop each at target loads of 9, 12, and 16 kips. Peak deflection and load data was stored at all three sites, while on the chip seal pavement, we also recorded time history data at two stations.

As seen in figure 4, the Dynatest FWD tested with the trailer oriented in the direction of traffic, while the JILS faced the opposite direction and drove in reverse behind the Dynatest machine. We did this to orient the two sensor bars in the same direction, thereby eliminating sensor bar orientation as a potential source of differences between deflection basins at the same test point.

Figure 4. Testing with both devices on Staley Road, Champaign, Illinois.

DATA ANALYSIS

ARA analyzed the data from both FWDs in four ways:

- Comparison of deflection profiles for each road normalized to 9,000 lbf
- Comparison of backcalculated subgrade modulus profiles for each road
- Comparison of average deflection basins for each pavement type
- Comparison of load time history data for the chip seal pavement

Deflection Profile Comparison

Figure 5 shows the maximum deflections from the JILS and Dynatest FWDs normalized to 9,000 lbf. The results of all three pavement types tested are shown on the same figure. It can be seen that both devices produced very similar deflection profiles for all three pavement types. In the case of the chip seal pavement—which produced deflections ranging from 36 to 52 mils—the JILS produced deflections averaging 1.47 mils higher than the Dynatest. This corresponds to an average percent difference of 3.4 percent. The AC pavement produced maximum deflections ranging from 12 to 22 mils. The average

JILS deflection was 0.38 mils higher than the Dynatest, corresponding to a 2.4 percent average difference. The PCC pavement produced the lowest deflections, ranging from 2 to 5 mils. The deflections from both devices were nearly identical, showing an average difference of just 0.06 mils, equivalent to a 0.01 percent difference.

The deflections at the 36-in sensor are shown in figure 6. Again the two FWDs show very similar trends for each pavement type. On the chip seal road, the JILS produced deflections averaging 0.32 mils higher than the Dynatest, corresponding to an average difference of 3.5 percent. In the case of the AC pavement, the average difference was 0.35 mils, equivalent to a 6.5 percent difference. Finally, the PCC pavement showed an average difference of 0.20 mils, corresponding to just a 0.1 percent difference.

Figure 5. Maximum deflection profiles at 9,000 lbf
Three pavement types.

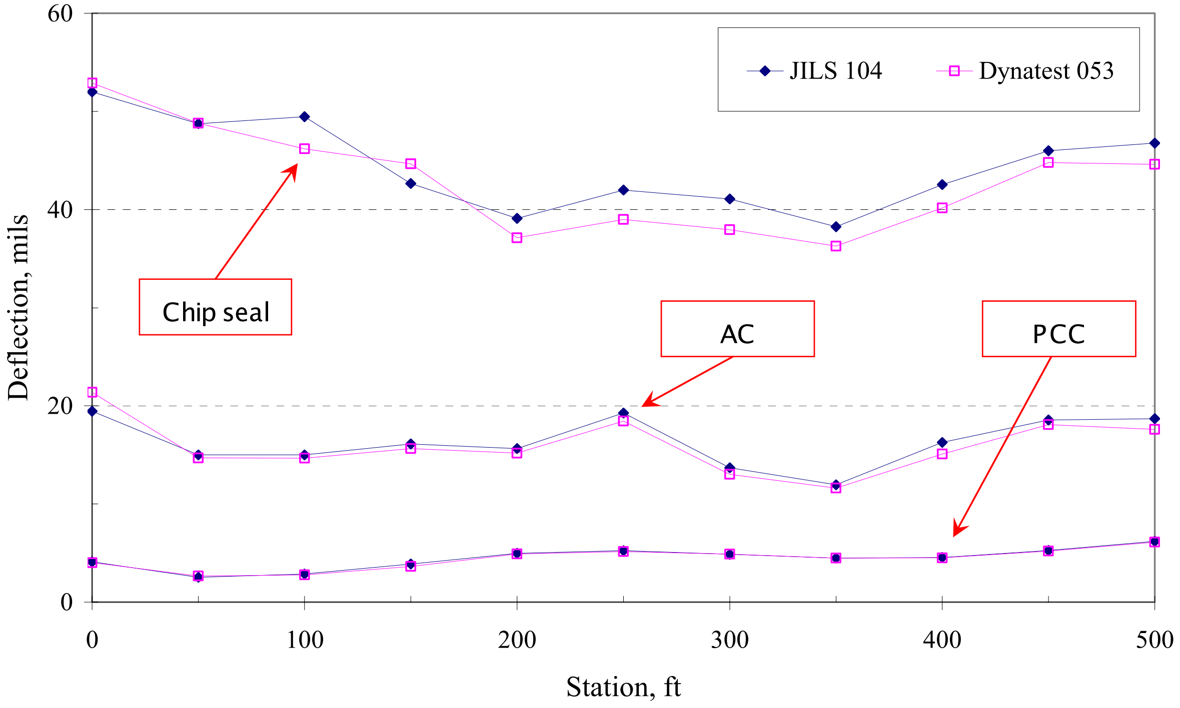
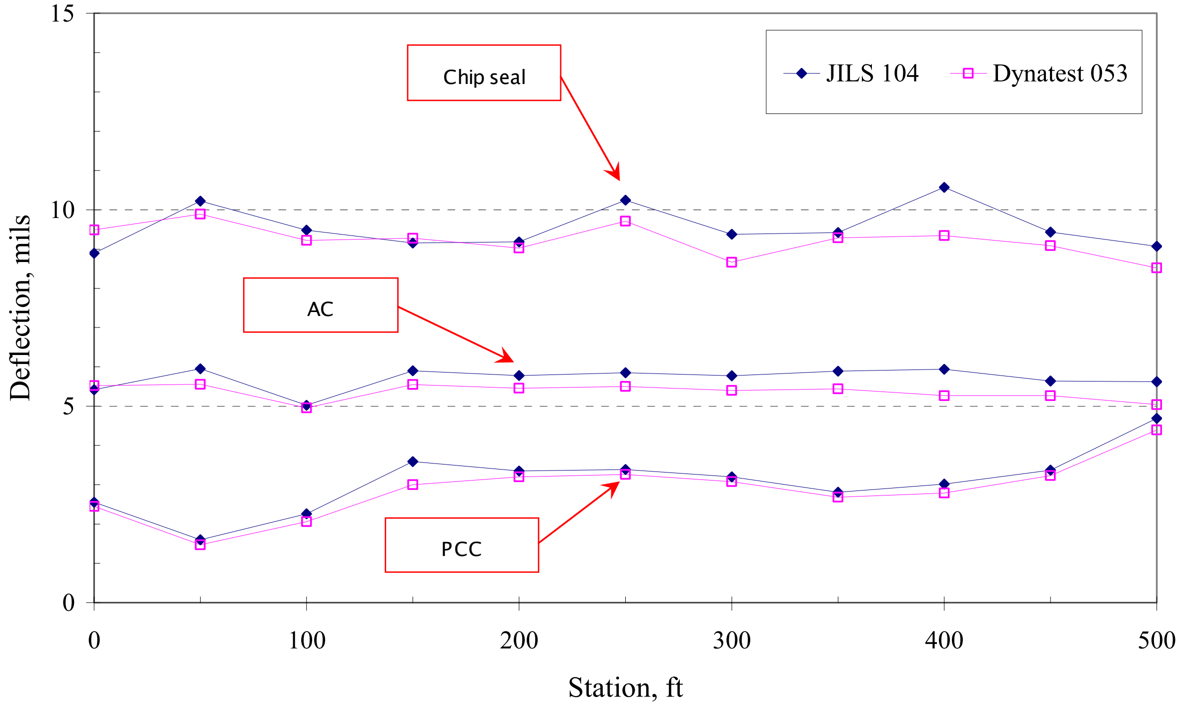


Figure 6. Deflection profiles at 36 in and 9,000 lbf
Three pavement types.



Subgrade Modulus Profile Comparison

The subgrade elastic modulus was determined using the following equation from the 1993 AASHTO flexible pavement backcalculation procedure and data from the 36-in sensor:

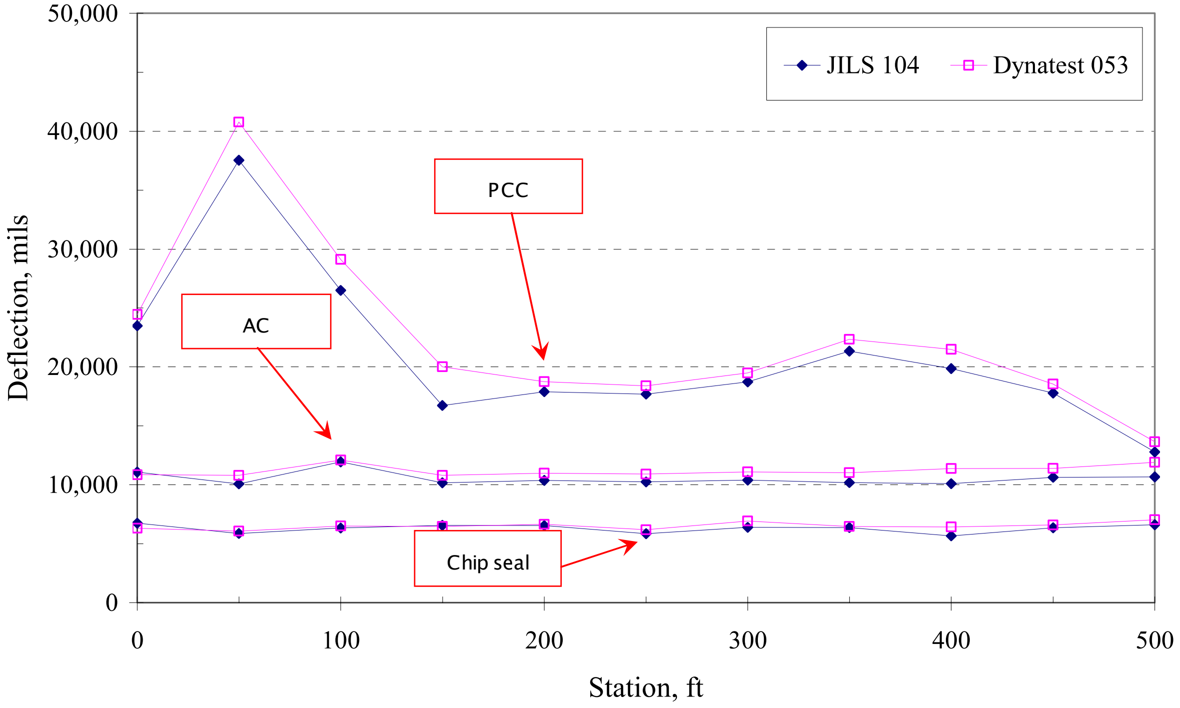
$$Es = (0.24 \text{ x } P) / (D_{36} \text{ x } r)$$

Where,

Es = Subgrade elastic modulus, psi
P = Load, lbf
D_{36} = Deflection at 36 in, inches
R = Radial distance from the load, 36 in

Figure 7 shows the backcalculated subgrade moduli for both FWDs on each road. Both FWDs produced very similar subgrade modulus profiles for the same road. In the case of the chip seal pavement, the JILs-determined subgrade moduli averaged 212 psi (3.3 percent) lower than the Dynatest. The difference on the AC pavement was 672 psi (6.0 percent), while the average difference on the PCC pavement of 1512 psi corresponded to a 0.1 percent difference.

Figure 7. Subgrade resilient modulus profiles based on the 36 in sensor. Three pavement types.

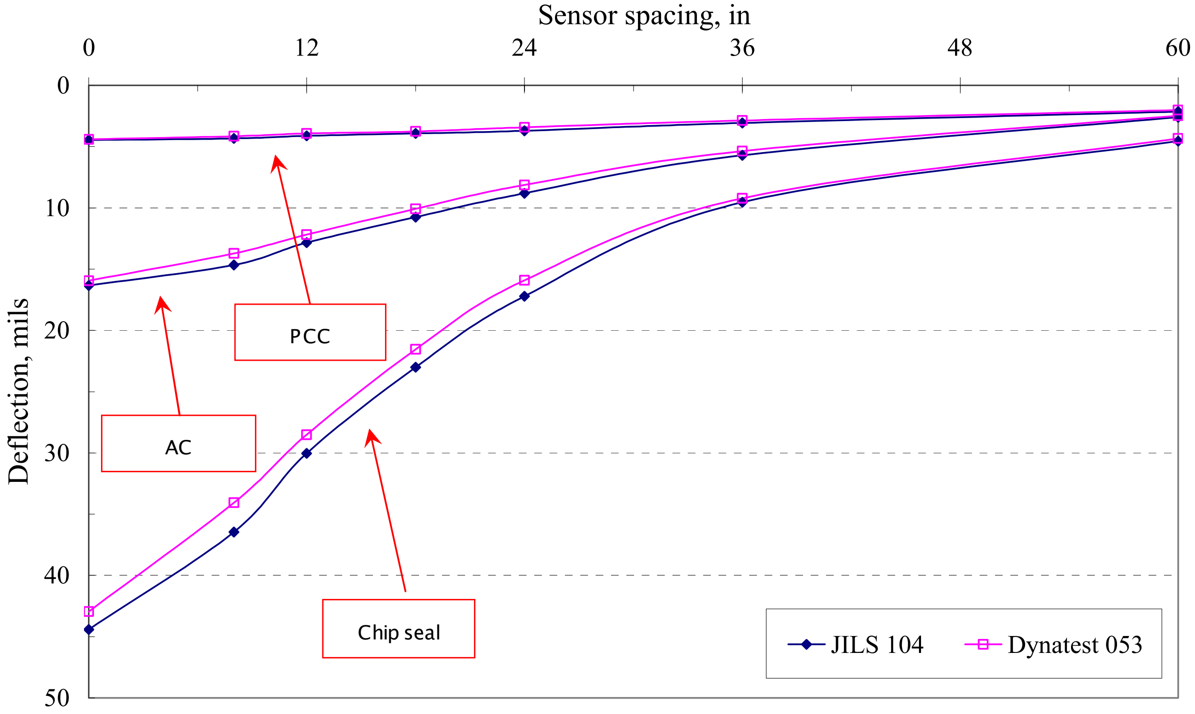


Deflection Basin Comparison

Another way of comparing deflections is by viewing the average deflection basin for each FWD at each test site. To do this, we normalized all deflections for each device to 9,000 lbf and then averaged the 11 test points at each site to produce a single deflection basin. As seen in figure 8, both devices produce very similar deflections from the 36-in sensor outward. Closer to the load plate, the magnitude and shape of the basins varies slightly for the chip seal and AC pavements. In each case, the JILS produced slightly higher deflections closer to the load, relative to the Dynatest. The JILS basin from 0 to 8 in also appears to be flatter than that of the Dynatest, especially in the case of the AC pavement. The shallow, flat deflection basin of the PCC pavement was nearly identical for both devices.

The average difference at each sensor between the JILS and Dynatest was calculated and an overall percent difference was calculated for the three test pavements. For the chip seal, AC, and PCC pavements, respectively, the average percent difference in deflections was 5.6, 5.9, and 0.1 percent. In each case the JILS produced the higher deflections.

Figure 8. Average deflection basins at 9,000 lbf.



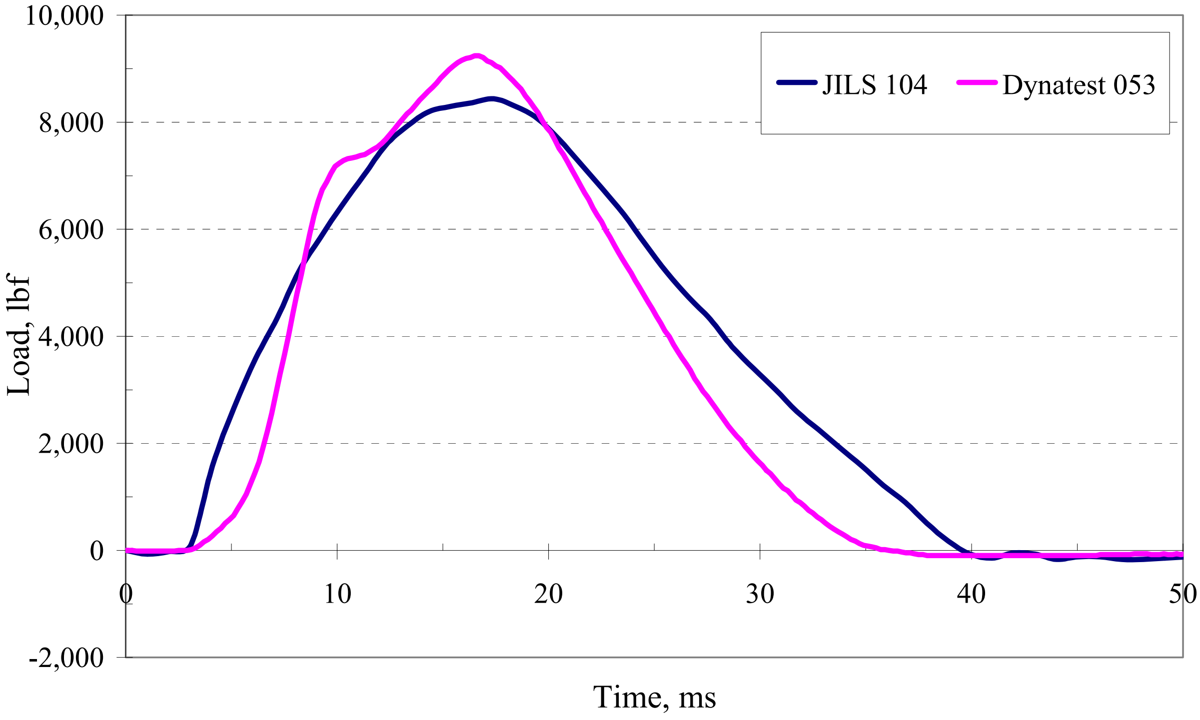
Load Time History Comparison

ARA stored load time history data for both devices at two locations on the chip seal road. The purpose of collecting time history data was to make a qualitative comparison between the load pulses generated by each device, including aspects such as shape, rise time, and symmetry. The average time histories for each device at a target load of 9,000 lbf are shown in figure 9.

Figure 9 shows that the JILS load pulse begins and ends at approximately 3 and 40 ms, respectively, with a peak value occurring at approximately 18 ms. This corresponds to load rise time and duration of 15 and 37 ms, respectively. It can also be seen that the JILS load pulse is very smooth and symmetrical.

The Dynatest load pulse begins and ends at 3 and 36 ms, respectively, with the peak load occurring at approximately 17 ms. This corresponds to a load rise time and duration of 14 and 33 ms, respectively. Although the load rise time is similar to the JILS, the shapes of the load pulses are very different in several aspects. First, the Dynatest pulse produces a “double-hump” shape, as the load rises quickly, tapers off, and then rises once again to peak load. In addition, its load time history increases very rapidly between 6 and 8 ms, showing a corresponding increase in load from 1,000 to 7,200 lbf over the same duration. This shows that approximately 67 percent (6,200 lbf / 9,200 lbf) of the peak load occurs over a very short duration (approximately 2 ms). On the other hand, the JILS load pulse is a very even rate of load from the time of initial load sensing to the moment of peak load.

Figure 9. Load time history comparison.
Chip seal.



Summary of Results

Tables 2 through 4 summarize the normalized deflections and backcalculated subgrade moduli for each test site.

Table 2. Statistical comparison of results – chip seal pavement.

Device	**Parameter**	**Deflection (mils) at a given sensor offset (in) @ 9,000 lbf**							**Es, psi**
		0	**8**	**12**	**18**	**24**	**36**	**60**	
JILS	Mean	44.42	36.47	30.04	23.01	17.21	9.55	4.55	6,301
	St. dev.	4.47	3.14	2.27	1.24	0.78	0.55	0.64	348
	CV	0.10	0.09	0.08	0.05	0.05	0.06	0.14	0.06
Dynatest	Mean	42.95	34.08	28.52	21.55	15.91	9.23	4.33	6,513
	St. dev.	5.28	3.41	2.39	1.24	0.61	0.40	0.27	288
	CV	0.12	0.10	0.08	0.06	0.04	0.04	0.06	0.04
Average absolute difference, mils		1.47	2.39	1.52	1.45	1.30	0.32	0.22	-212
Average percent difference, %		3.4	7.0	5.3	6.7	8.2	3.5	5.1	-3.3

Note: Average percent difference of all sensors is 5.6 percent.

Table 3. Statistical comparison of results – AC pavement.

Device	**Parameter**	**Deflection (mils) at a given sensor offset (in) @ 9,000 lbf**							**Esub, psi**
		0	**8**	**12**	**18**	**24**	**36**	**60**	
JILS	Mean	16.33	14.66	12.84	10.76	8.81	5.71	2.60	10,533
	St. dev.	2.43	1.82	1.31	0.80	0.45	0.28	0.21	554
	CV	0.15	0.12	0.10	0.07	0.05	0.05	0.08	0.05
Dynatest	Mean	15.95	13.73	12.18	10.07	8.14	5.36	2.48	11,205
	St. dev.	2.74	1.65	1.21	0.71	0.39	0.21	0.20	446
	CV	0.17	0.12	0.10	0.07	0.05	0.04	0.08	0.04
Average absolute difference, mils		0.38	0.94	0.67	0.68	0.67	0.35	0.12	-672
Average percent difference, %		2.4	6.8	5.5	6.8	8.2	6.5	4.9	-6.0

Note: Average percent difference of all sensors is 5.9 percent.

Table 4. Statistical comparison of results – PCC pavement.

Device	**Parameter**	**Deflection (mils) at a given sensor offset (in) @ 9,000 lbf**							**Esub, psi**
		0	**8**	**12**	**18**	**24**	**36**	**60**	
JILS	Mean	4.46	4.34	4.12	3.93	3.70	3.08	2.14	20,942
	St. dev.	1.07	1.07	1.04	0.99	0.92	0.80	0.63	6,580
	CV	0.24	0.25	0.25	0.25	0.25	0.26	0.30	0.31
Dynatest	Mean	4.40	4.15	3.92	3.77	3.43	2.88	2.02	22,454
	St. dev.	1.05	1.03	1.02	0.96	0.88	0.75	0.56	7,230
	CV	0.24	0.25	0.26	0.25	0.26	0.26	0.28	0.32
Average absolute difference, mils		0.06	0.19	0.20	0.16	0.28	0.20	0.12	-1512
Average percent difference, %		0.0	0.0	0.0	0.0	0.1	0.1	0.1	-0.1

Note: Average percent difference of all sensors is 0.1 percent.

SUMMARY AND DISCUSSION OF RESULTS

As a result of this study, ARA determined that the deflections produced by the JILS and Dynatest FWDs─while not identical─are very similar. Specifically, an evaluation of deflection profiles, backcalculated subgrade moduli, average deflection basins, and load time history data on three distinct pavement types provided satisfactory data for ARA to conclude that the JILS FWD provides high-quality data that can be used effectively for pavement evaluation and design purposes. Based on this study, we placed the JILS FWD into service.

Summary

Specific findings of this study include:

- On the PCC pavement, both the normalized deflections and backcalculated subgrade moduli of both FWDs were within 0.1 percent of each other; in other words, a negligible difference.

- In the case of the AC pavement, the JILS maximum deflection averaged 2.4 percent higher than the Dynatest, and the average percent difference of all seven sensors was 5.9 percent. The chip seal pavement produced similar differences, showing the JILS maximum deflection to be 3.4 percent higher than the Dynatest, and an average percent difference of 5.6 percent for all seven sensors.

- In terms of the effect of deflection difference on backcalculated subgrade moduli, the JILS-determined subgrade moduli averaged 3.3 and 6.0 percent different for the chip seal and AC pavements, respectively.

- The average deflection basins of each device were very similar, especially from the 36-in sensor outward. On the chip seal and AC pavements the deflections near the load plate were slightly higher for the JILS and its basin was flatter between the 0 and 8 in sensors. For the chip seal, AC, and PCC pavements, respectively, the average percent difference in deflections was 5.6, 5.9, and 0.1 percent. In each case the JILs produced the higher deflections.

- The load pulses of the JILS and Dynatest produced load rise times of approximately 15 and 14 ms, respectively. However, the shapes and loading rates varied significantly. The JILS produced smooth, single-peaked pulse with an even loading rate. The Dynatest load pulse contained a double-peak and a much rapid loading rate, prior to peak load.

Discussion of Results

It should be noted that differences in deflections do not indicate that one FWD is more correct than the other. As both machines were calibrated at a SHRP calibration center within a short period of time of the comparison, they can both be considered to accurately measure deflections within a very tight tolerance (generally less than 0.3 percent error), as ensured by the calibration centers. Therefore, the differences in deflection between the two FWDs indicate that the actual deflections being produced by each device differ slightly. Deflections are a function of both pavement factors (e.g., layer thicknesses) and equipment characteristics (e.g., load pulse shape and rise time). Given that the pavement factors were the same for both devices, and in light of the fact that both FWDs were determined to be measuring accurately through SHRP calibration, the differences in deflection between the two machines is attributed to their load generating mechanisms.

Although pinpointing the exact reasons for the differences between the two FWDs' deflections was beyond the scope of this study, the potential differences include the height and mass used to achieve target load (the JILS lifts a heavier mass a shorter distance to achieve the same force as the Dynatest), the buffer type and number, the load plate stiffness, the amount of mass below the buffers, and the preload placed on the pavement prior to the application of dynamic loads.

It is important to note that the JILS comes equipped with an air bag mechanism used to center the loading column on uneven pavement surfaces, and that this airbag system can be adjusted to vary the preload transferred from the truck's rear tires to the FWD load plate. Initial testing of the JILS revealed that deflections on some pavements (specifically, thin AC pavements on weak subgrades) are significantly affected by the amount of preload. To obtain a similar preload as the Dynatest, the air bag pressure in the JILS should be adjusted to 5-10 psi, which was done for this study.

Finally, ARA notes that, in our experience, even multiple FWDs produced by the same manufacturer do not necessarily produce identical deflections, especially if the devices differ in age. This can be due to a variety of reasons, including changes in design or manufacturing methods, equipment upgrade, maintenance, repair, and calibration. Therefore, while we recognize that reproducibility between devices is important, we understand that exact reproducibility, even with devices from the same manufacturer, is not necessarily expected or needed for typical pavement evaluation and design projects.