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**DATA HANDLING PROCEDURES FOR THE TEXAS
ACCELERATED PAVEMENT TEST CENTER (TXAPT)**

Authors:

Thomas W. Rioux
W. Ronald Hudson
Ronald P. White

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Performing Organization: Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, Texas 78705-2650	Sponsoring Organization: Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080	
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Abstract: This report defines the Texas Accelerated Pavement Test Center (TxAPT) data procedures so users of TxAPT data can understand the handling and storage of "raw, cleansed, and processed" data.	Keywords: APT, data procedures, data, raw, cleansed, processed, MLS, accelerated pavement testing	No. of Pages: 30

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1. Introduction

This report is to define the Texas Accelerated Pavement Test Center (TxAPT) Data Procedures so users of TxAPT data can understand the handling and storage of “raw, cleansed, and processed” data.

Definitions

The following definitions are used throughout this report:

- “Raw Data” the first electronically-recorded human-readable data saved on a computer disk or other computer storage device; no data values have been deleted, changed, or re-arranged.
- “raw data” can be a spreadsheet of any values such as dates, times, and axle counts entered directly by the user or transcribed from handwritten records.
- “raw data” can also be measurements from any transducer or recorder that automatically saves the data in electronic format such as ASCII text fixed-column, comma-separated, or tab-separated file format.
- “Rejected Data” “raw data” that does not meet the predefined data collection criteria for the measurement device; “rejected data” will be deleted and not be stored; the data collection process will be repeated until the resulting data meets the data collection criteria.
- “rejected data” can be “raw data” for a transverse profile where the first reading on the starting point does not match the last reading when the instrument returns to the starting point and the difference exceeds the specified amount. In some cases, such data can be corrected.
- “Cleansed Data” “raw data” that has been manipulated by through well defined “data cleansing procedures” to rid the “raw data” of identifiable errors; the “data cleansing procedures” generally involve the “raw data” being reviewed by a person or process, often with the aid of computational procedures and/or statistical methods, and had insignificant data removed that does not affect the primary data and/or that is obviously the result of a faulty instrument or recording process; after the “data cleansing procedures”, the “cleansed data” can exactly match the “raw data” if no items needing cleansing.
- “data cleansing procedures” can be the removal of blank lines between rows of data.
- “data cleansing procedures” can be the deletion of a data record when 1 of several recording devices or sensors did not function or record properly and data from the devices is needed for next step.

“data cleansing procedures” can be the process of determining that a measurement value is statistically a blunder; for example, greater than $\pm 3\sigma$ from the mean, and replacing the measurement value with a number representing a bad measurement such as -999 for temperature or percent moisture.

“data cleansing procedures” can involve replacing a blank or bad value for a factor such as time when data is collected for example every 15 minutes, the previous data record has a correct date and time, the next data record has a correct date and time, and the next data record is 30 minutes later than the previous data record.

“data cleansing procedures” can be converting a value from English to metric units.

“data cleansing procedures” can be the re-formatting of data from a manufacturer’s format into a format needed for another “data processing procedure”.

“Processed Data” “cleansed data” that has been manipulated by defined “data processing procedures” to produce the final desired data; some data types may not have to be manipulated to go from “cleansed data” to “processed data” therefore the “processed data” can exactly match the “cleansed data”.

“data processing procedures” can be converting a value from English to metric units.

“data processing procedures” can be converting a year and Julian day number to a year, month, and day number.

“data processing procedures” can be the correction of transverse profile measurements to account for the small error when the first reading on the starting point does not match the last reading when the instrument returns to the starting point.

“data processing procedures” can be the correction of transverse profile measurements to account for the bending of the beam by the weight of the measurement device as it moves across the beam.

“data processing procedures” can be the determination of the maximum rut depth within a wheel path using the transverse profile data.

TxAAPT Web Sites

TxAAPT will maintain two web sites designated (1) the TxAAPT Researchers' Web Site and (2) the TxAAPT Public Web Site. The following diagram (Figure 1-1) illustrates the relationship between the data and the web sites and the access by researchers and the general public.

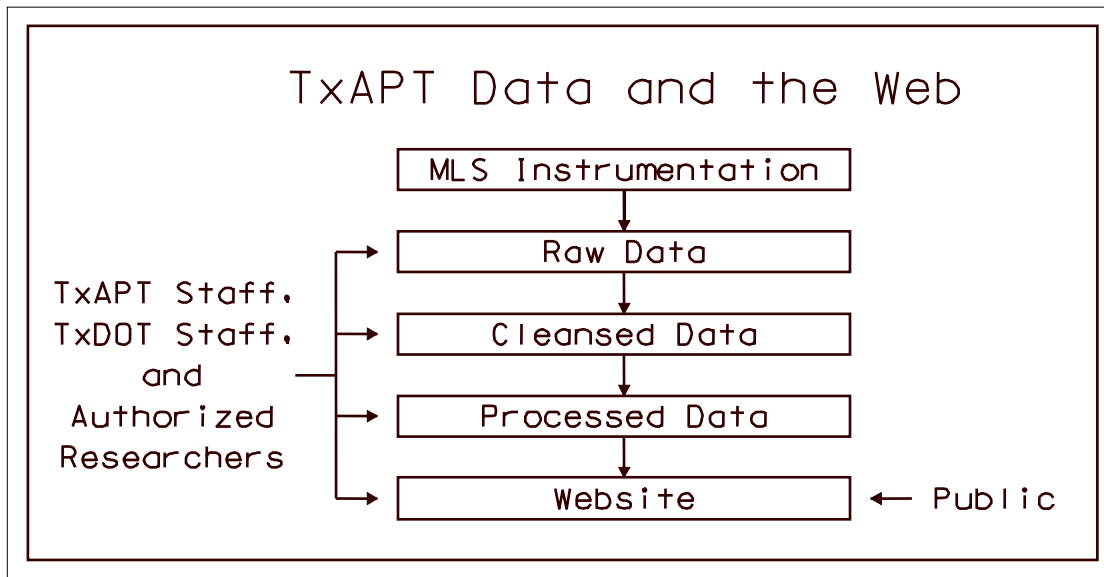


Figure 1-1: Access to APT data by researchers and the general public

The TxAAPT Researchers' Web Site is:

- Only accessible by TxAAPT staff, TxDOT staff, and authorized researchers while the world is denied access.
- Only TxAAPT staff will be able to store data on the TxAAPT Researchers' Web Site while TxAAPT staff, TxDOT staff, and authorized researchers may view and download data.
- The data available at the TxAAPT Researchers' Web Site includes raw, cleansed, and processed data.
- The TxAAPT Researchers' Web Site user may download raw and/or cleansed data, view or print selected processed data in tabular format, view or print selected processed data in chart format, or download selected processed data in ASCII text comma-separated file format.

The TxAAPT Public Web Site is:

- Accessible to the world.
- Only TxAAPT staff may store data on the TxAAPT Public Web Site while the world may view and download data.
- Only processed data is available at the TxAAPT Public Web Site.
- The TxAAPT Public Web Site user may view or print selected processed data in tabular format, view or print selected processed data in chart format, or download selected processed data in ASCII text comma-separated file format.

2. Data Collection, Data Cleansing, Data Processing, and Data Storage

Texas Department of Transportation (TxDOT) personnel, or other identified persons, will gather the raw data and transmit it in electronic form to TxAPT within 2 working days of data collection. The following procedures will be used:

1. The raw data will be posted on the TxAPT Researchers' Web Site for downloading in the data's original format using standard File Transfer Protocol (FTP) procedures.
2. TxAPT staff will perform the data cleansing procedures to produce the cleansed data and post the cleansed data on the TxAPT Researchers' Web Site for downloading using standard FTP procedures.
3. TxAPT staff will perform the data processing procedures to produce the processed data and add the processed data to the TxAPT web database on the TxAPT Researchers' Web Site.
4. Upon agreement between TxAPT staff, TxDOT staff, and the researchers, TxAPT staff will add the processed data to the TxAPT web database on the TxAPT Public Web Site.

The following types of raw data might be collected at various times within a test plan:

1. CAPTELS Weigh-in-Motion (WIM) scales
 - a. Dynamic weights
 - b. Static weights
2. Cracking
 - a. Camera
 - b. Manual
3. Digital Incremental Profiler (Dipstick) (Dipstick is a Registered Trademark of Face Construction Technologies, Inc.)
 - a. Longitudinal
 - b. Transverse
4. Dynamic Cone Penetrometer (DCP)
5. Environment
 - a. Moisture
 - b. Temperature
6. Falling Weight Deflectometer (FWD)
 - a. Standard FWD
 - b. Whole history FWD
7. Ground Penetrating Radar (GPR)
8. Load
 - a. Hydraulic pressure reading
 - b. Axle-mounted Strain Gauges
9. Multiple-Depth Deflectometer (MDD) using Linear Variable Displacement Transducers (LVDTs)

- 10. Operational
 - a. Beginning date, time, and axle count
 - b. Ending date, time, and axle count
- 11. Profile
 - a. Longitudinal
 - b. Transverse
- 12. Rolling Dynamic Deflectometer (RDD)
- 13. Seismic
 - a. Full-Depth Seismic Pavement Analyzer (SPA)
 - b. Portable Seismic Pavement Analyzer (PSPA)
 - c. Spectral Analysis of Surface Waves (SASW)
- 14. Weather
 - a. Air temperature
 - b. Barometric pressure
 - c. Humidity
 - d. Radiation
 - e. Rainfall
 - 1) 15 minute total
 - 2) 24 hour total
 - f. Wind
 - 1) Direction
 - 2) Speed

CAPTELS Weigh-in-Motion (WIM) Scales

CAPTELS Weigh-in-Motion (WIM) scales can measure both dynamic loads and static loads. The raw data from the CAPTELS WIM scales is an ASCII text file with one measurement per file comprised of multiple lines. The words are in French with header information lines and data value lines.

Most of the data provided by TxDOT is in spreadsheet format where the raw data from a single file has been transformed into a single line of text in semicolon-separated format. The single line of text is stored in a single cell in the spreadsheet as text. Several of the data fields in the single line of text have information indicating the type of data in the field such as “Date:” and “Time:”. Later versions of the spreadsheet have the single line of text stored in multiple cells in the spreadsheet as text or numbers.

The data is gathered by the TxDOT MLS crew. The data is not stored in the TxAPT Web-based Database.

Cracking

Cracking data can be measured using a camera or using manual methods. Using either method, the intent is to measure the existence and progression of cracking. Cracking patterns include:

1. alligator cracking,
2. longitudinal cracking,
3. transverse cracking, and
4. other cracking.

The data is gathered by the TxDOT MLS crew. The data is not stored in the TxAPT Web-based Database.

Digital Incremental Profiler (Dipstick)

Profile data can be measured using a Digital Incremental Profiler (Dipstick). Dipstick is a Registered Trademark of Face Construction Technologies, Inc. The Dipstick can be used to measure longitudinal as well as the transverse profiles. Measurements begin at the starting point, proceed to the ending point, and return to the starting point. The measurement value is the elevation difference (in thousandths of an inch) between the Dipstick's two support legs that are exactly one foot apart thus the summation of the measurement values from the starting point, to the ending point, and returning to the starting point should be zero. Audible and visual signals alert the operator when each elevation difference reading is measured and automatically recorded.

Longitudinal profiles are generally taken along 3 transverse positions labeled left (generally the left wheel path), center, and right (generally the right wheel path). The data provided by TxDOT is in spreadsheet format and is apparent that this is not the raw data. Most of the time, the first column of data is labeled "L" or left but in a few cases it is labeled "R" or right. The center column of data is labeled "C" or center. Most of the time, the last column of data is labeled "R" but in a few cases it is labeled "L". Occasionally, there are two columns of numbers for left, center, and right. Often there are comments in an adjacent column indicating locations of the CAPTELS or other noteworthy comments such as "may be wrong."

The data processing procedures can be:

1. Convert the longitudinal measurement position from feet to meters by multiplying the value by 0.3048.
2. If the elevation measurements are made at equal distances then correct each elevation difference by subtracting the total of the elevation differences for a complete round trip (should be zero) divided by the number of data points for a complete round trip.
3. If the elevation measurements are not made at equal distances then correct each elevation difference by subtracting the total of the elevation differences for a complete round trip (should be zero) times the horizontal distance from the previous measurement point divided by the total horizontal distance for a complete round trip.
4. Convert the elevation differences from inches to millimeters by multiplying by 25.4.
5. Sum all elevation differences from the starting point to the specified measurement point to get the elevation.

It has been discovered that although the data for an entire round trip is used to determine the closing error, only the outbound data is used to calculate elevation relative to the starting point. Since each measurement is theoretically 1 foot in length and assuming 80 sections, outbound section 1 and inbound section 80 measure the same 1 foot section with the outbound measuring in one direction and the inbound measuring in the opposite direction. The elevation difference for section 1 can be calculated as $((\text{section_1_elevation_difference}) - (\text{section_80_elevation_difference}))/2$, the elevation difference for section 2 can be calculated as $((\text{section_2_elevation_difference}) - (\text{section_79_elevation_difference}))/2$, the elevation difference for section 39 can be calculated as $((\text{section_39_elevation_difference}) - (\text{section_42_elevation_difference}))/2$, and the elevation difference for section 40 can be calculated as $((\text{section_40_elevation_difference}) - (\text{section_41_elevation_difference}))/2$. This can give a more accurate elevation difference.

The data is gathered by the TxDOT MLS crew.

The site name (Site), distance (L, C, or R) (Distance), axle count (Axlecount), longitudinal position in meters (X-values), and elevation relative to the starting point in millimeters (Y-values) (the summation of all elevation differences from the starting point) are stored in the TxAPT Web-based Database in the Dipstick table.

Dynamic Cone Penetrometer (DCP)

Dynamic Cone Penetrometer (DCP) tests can be used to determine the in-situ bearing capacity and thickness of the unbound layers of pavement base, subbase, and subgrades using a drop hammer to drive a 60° conical tip into the ground. Readings are taken in mm for each blow of the hammer and read directly from the graduated steel rule attached to the instrument. The data recorded is the location, hammer weight, number of blows, and penetration value.

The California Bearing Ratio (CBR) can be calculated using the relationship between DCP slope and CBR using a model similar to:
$$\text{Log CBR} = 2.628 - 1.273 \log (\text{DCP})$$

The data is gathered by the TxDOT MLS crew. The data is not stored in the TxAPT Web-based Database.

Environment

Environmental measurements include moisture and temperature.

Moisture measurements are made at various depths within the base and subgrade using the University of Houston Moisture Sensors and are recorded as a percentage.

Temperature measurements are made of the air inside the TxMLS, the pavement surface, and the pavement structure at various depths within the asphalt, base, and subgrade and are recorded in degrees Fahrenheit. The air temperature outside the TxMLS is part of the Weather data.

The moisture and temperature data are automatically recorded by computer monitoring equipment and include the date and time of the recording.

It is suggested the data cleansing procedures be as follows:

1. If the date information is year and Julian day then converting Julian day to a month and day.
2. If there is a standard recording period for the data (say every X minutes) then replacing a blank or bad value for date when (a) data is collected every X minutes, (b) the previous data record has a correct date and time, (c) the next data record has a correct date and time, and (d) the next data record is $2 \times X$ minutes later than the previous data record.
3. If there is a standard recording period for the data (say every X minutes) then replacing a blank or bad value for time when (a) data is collected every X minutes, (b) the previous data record has a correct date and time, (c) the next data record has a correct date and time, and (d) the next data record is $2 \times X$ minutes later than the previous data record.
4. Deleting one hour of data that has duplicate times when the time is set back one hour because of Daylight Savings Time each Fall on the last Sunday in October.
5. Investigate problems when the date and time for the current record is equal or before the date and time for the previous record.
6. Replacing a blank or non-numeric value for moisture with a number representing a bad measurement such as -999.
7. Replacing a value for moisture that is below the minimum moisture value (say 0) with a number representing a bad measurement such as -999.
8. Replacing a value for moisture that is above the maximum moisture value (say 100) with a number representing a bad measurement such as -999.
9. For the same moisture sensor, replacing a bad value for moisture with a number representing a bad measurement such as -999 if a statistical test shows that the value is bad.
10. Replacing a blank or non-numeric value for temperature with a number representing a bad measurement such as -999.
11. Replacing a value for temperature that is below the minimum temperature ever recorded (-23 degrees for Texas) minus 10 degrees (for example) with a number representing a bad measurement such as -999.
12. Replacing a value for temperature that is above the maximum temperature ever recorded (120 degrees for Texas) plus 10 degrees (for example) with a number representing a bad measurement such as -999.
13. For the same temperature sensor, replacing a bad value for temperature with a number representing a bad measurement such as -999 if a statistical test shows that the value is bad.

The site name (Site), date (DateOfTestSD, DateOfTestTX, and DateTimeOfTestGD), time (TimeOfTestST and DateTimeOfTestGD), moisture (moisture_TDR1 through moisture_TDR8), and temperature (mls_temp, outTemp_top, outTemp_mid, outTemp_bot, mlsTemp_sur,

mlsTemp_top, mlsTemp_mid, and mlsTemp_bot) are stored in the TxAPT Web-based Database in the WeatherData table.

Falling Weight Deflectometer (FWD)

The Falling Weight Deflectometer (FWD) is a non-destructive testing device that is capable of applying dynamic impulse loads to the pavement surface, similar in magnitude and duration to that of a single heavy moving wheel load. (See Figures 2-1 and 2-2). The response of the pavement system is measured in terms of vertical deformation, or deflection, over a given area using seismometers. The FWD can be used to determine a deflection basin caused by a controlled load. FWD generated data, combined with layer thickness, can be used to obtain the in-situ resilient elastic module of a pavement structure.

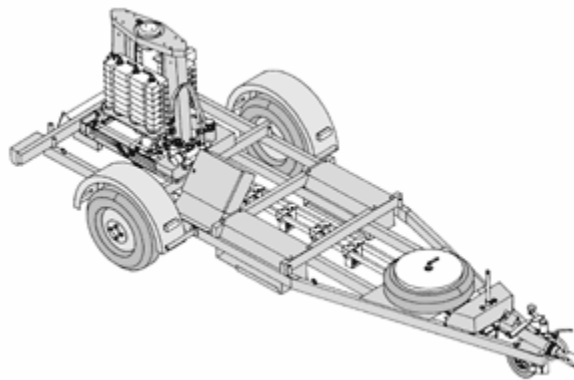


Figure 2-1: Falling Weight Deflectometer



Figure 2-2: FWD Load Plate and Sensors

FWD tests can be (1) Standard where only the peak deflections are recorded and (2) Whole History where all deflection data is recorded. Typically, the following FWD tests are performed:

1. a Whole History FWD test in the left, center, and right wheel path at the 6 meter line,
2. a Standard FWD test across the MDDs in the left and right wheel path where the seismometers cross the MDD location, and
3. a Standard FWD test in the left, center, and right wheel path at 12 meter line.

FWD data consists of the Distance (0, 1.5, 3.0, 4.5, 6.0, 7.5, 9.0, 10.5, and 12.0), Position (L, C, or R), Load in kN, the value from the geophones R1 through R7 in mm, Temperature in degrees Celsius, and Coefficient (-0.0254 for MLS Jacksboro N1) and Constant (1.7088 for MLS Jacksboro N1) for temperature correcting the data. The data is automatically recorded by computer monitoring equipment. The Temperature, Coefficient, and Constant values are used in the following equation to correct the measurements to a specific temperature:
Value = Value * (Constant + Coefficient * Temperature)

It is suggested the data cleansing procedures be:

1. Deleting a record if the Load is blank, zero, or non-numeric.
2. Replacing a blank or non-numeric value for R1 through R7 with a number representing a bad measurement such as -999.
3. Replacing a value for R1 through R7 that is below the minimum value (say 0.0001 or 0.0000) with a number representing a bad measurement such as -999.
4. Replacing a value for R1 through R7 that is above the maximum value (say 1.5000) with a number representing a bad measurement such as -999.
5. Replacing a blank or non-numeric value for Temperature with a number representing a bad measurement such as -999.
6. Replacing a value for Temperature that is below the minimum temperature ever recorded (-23 degrees for Texas) minus say 10 degrees with a number representing a bad measurement such as -999.
7. Replacing a value for Temperature that is above the maximum temperature ever recorded (120 degrees for Texas) plus say 10 degrees with a number representing a bad measurement such as -999.

The site name (Site), Distance, Position, axle count (Axlecount), Load, the value from the geophones R1 through R7, Temperature, Coefficient, and Constant are stored in the TxAPT Web-based Database in the FWD table.

Ground Penetrating Radar (GPR)

Ground Penetrating Radar (GPR) is a noninvasive electromagnetic geophysical technique for subsurface exploration, characterization, and monitoring. It is deployed either from the surface, by hand or vehicle, in boreholes, and between boreholes. It has the highest resolution of any geophysical method for imaging the subsurface, with centimeter scale resolution sometimes possible.

Resolution is controlled by wavelength of the propagating electromagnetic wave in the ground. Resolution increases with increasing frequency (shorter wavelength). Depth of investigation varies from less than one meter in mineralogical clay soils like montmorillonite to more than 5,400 meters in polar ice. Depth of investigation increases with decreasing frequency but with decreasing resolution. Typical depths of investigation in fresh-water saturated, clay-free sands are about 30 meters. Depths of investigation (and resolution) are controlled by electrical properties through conduction losses, dielectric relaxation in water, electrochemical reactions at

the mineralogical clay-water interface, scattering losses, and (rarely) magnetic relaxation losses in iron bearing minerals. Scattering losses are the result of spatial scales of heterogeneity approaching the size of the wavelength in the ground (like the difference between an ice cube and a snowball in scattering visible light). Detectability of objects in the ground depends upon their size, shape, and orientation relative to the antenna, contrast with the host medium, as well as radiofrequency noise and interferences.

The data is gathered by TxDOT.

The data is not stored in the TxAPT Web-based Database.

Load

In the old TxMLS, the load was set by rotating a bogie over the CAPTELS Weigh-in-Motion (WIM) scales and adjusting screws on large springs, which push against the weight of the TxMLS device to create the desired load. This procedure was performed for each bogie each time the TxMLS was raised and lowered for data measurement or other reasons. As the pavement rutted, the load can decrease from the adjusted value and required periodic adjustment.

In the new TxMLS, the load is set by rotating a bogie over the CAPTELS scales and adjusting the hydraulic pressure in the hydraulic rams. The hydraulic rams push against the weight of the TxMLS device to create the desired load. This procedure may have to be performed for each bogie each time the TxMLS is raised and lowered for data measurement or other reasons. As the pavement ruts, the load should not increase or decrease from the adjusted value.

In the new TxMLS, strain gauges have been attached to each axle of every bogie that should measure the load after being calibrated.

The TxDOT MLS crew gathers this data.

This data is not stored in the TxAPT Web-based Database but it is part of the web pages because it is critical information for the test plan.

Multiple-Depth Deflectometer (MDD)

Multi-Depth Deflectometers (MDDs) are used to measure “in-situ” elastic deformation and/or permanent deformations in the various pavements layers of a test section. The basis of the patented MDD system is a series of Linear Variable Differential Transformer (LVDT) modules, which are mounted on a rod in a 1.5 inch (39 mm) diameter hole in the test section. The LVDT converts a measured voltage source to a linear displacement output. Up to six, but normally 3, LVDT modules can be mounted at various depths in the hole. Ideally, an LVDT is placed at each layer interface, so that the deflection contribution of each layer can be measured directly. The modules are anchored to the soil by way of small steel balls, which are forced out against the walls of the hole. The reference rod is anchored into the subgrade approximately 10 feet (3 m) below the pavement surface where no deflection is likely to occur. The reference rod is connected to the anchor using a snap head connector so that the MDD modules can be removed for re-use. The LVDT module measures the displacement of the soil relative to the rod to an

accuracy of +/- 0.0003937 inches (+/- 10 microns). The top of the hole is sealed with a cap, which contains the connector to the data acquisition system.

During testing, the permanent deformation at each LVDT module is recorded, as are the elastic deformation basins under the test wheel loads. The plastic deformation data have been used to develop transfer functions relating load repetition to plastic strain in the road building materials. The deflection data can be used to determine the effective elastic moduli for each pavement layer.

The TxDOT MLS crew gathers this data. This data is not stored in the TxAPT Web-based Database.

Operational

The operational data consists of the date, time, and axle count when the TxMLS is started and the date, time, and axle count when the TxMLS is stopped while the speed is approximately constant. It is assumed that the TxMLS will not be operated for the early morning hours of the Sunday when Daylight Savings Time is set back one hour each Fall and set forward one hour each Spring.

It is suggested that the data cleansing procedures be:

1. If the date information is year and Julian day then converting Julian day to a month and day.
2. Checking the time if the TxMLS is operated on the early morning hours of the Sunday when Daylight Savings Time is set back one hour each Fall and set forward one hour each Spring
3. Investigate problems if the beginning date and time for the current record is before the ending date and time for the previous record.
4. Investigate problems if the ending date and time for the current record is before the beginning date and time for the current record.
5. Investigate problems if the beginning axle count for the current record is not the ending axle count for the previous record.
6. Investigate problems if the ending axle count for the current record is before the beginning axle count for the current record.

It is suggested that the data processing procedures be:

1. Sum the axle count since the beginning of the test to create the cumulative axle count.

The TxDOT MLS crew collects this data.

The date (DateOfTestDT and DateOfTest), starting time (startTime), ending time (stopTime), axle count (NrAxles), and cumulative axle count (CumNrAxles) data are stored in the TxAPT Web-based Database in the OperationalData table.

Profile

Both the longitudinal and transverse profile may be measured at specified intervals. The profile consists of elevation changes relative to the beginning point that is assumed to not change in elevation over time. The profile data starts and ends on the same beginning reference point normally elevation 0.0. The Digital Incremental Profiler (Dipstick) can be used to measure both the longitudinal and transverse profile. A profiler can also be used to measure transverse profile.

If the calculated elevation of the beginning reference point at the end of the measurements after a complete round trip is greater than the calculated elevation of the beginning reference point at the beginning of the measurements by a specified tolerance, then reject the data and repeat the measurements.

The data processing procedures can be:

1. Convert the longitudinal or transverse measurement position from feet to meters by multiplying the value by 0.3048.
2. If the elevation measurements are made at equal distances then correct each elevation difference by subtracting the total of the elevation differences for a complete round trip (should be zero) divided by the number of data points for a complete round trip.
3. If the elevation measurements are not made at equal distances then correct each elevation difference by subtracting the total of the elevation differences for a complete round trip (should be zero) times the horizontal distance from the previous measurement point divided by the total horizontal distance for a complete round trip.
4. Convert the elevation differences from inches to millimeters by multiplying by 25.4.
5. Sum all elevation differences from the starting point to the specified measurement point to get the elevation.

The TxDOT MLS crew collects this data.

For the transverse profile, the longitudinal distance (Distance), axle count (Axle count), transverse distance (X-values), and elevation (Y-values) are stored in the TxAPT Web-based Database in the TransverseProfile table.

Rolling Dynamic Deflectometer (RDD)

The Rolling Dynamic Deflectometer (RDD) is a truck-mounted deflectometer that applies large cyclic loads to the pavement using a servo-hydraulic loading system and continuously measures the induced cyclic deflections as it moves along the entire pavement using force and deflection measurement systems (Bay et al. 2000). An advantage of the RDD is that it can measure the spatial variability in deflection caused by pavement features such as joints, cracks, patches, and changing construction or subgrade conditions.

The hydraulic actuator drives a 3400-kg (7500-lb) mass up and down, generating vertical dynamic forces up to 308 kN (34.7 kips) peak-to-peak at frequencies from 5 to 100 Hz. These vertical dynamic forces are transferred down the stilt structure to a loading frame, which is

supported by two loading rollers. The two loading rollers apply the dynamic (and static) forces to the pavement. The loading rollers are held in contact with the pavement by means of a static hold-down force, which is generated by hydraulic actuators reacting against the mass of the truck. The vertical downward force is applied to the load frame through four air springs. The combined static and dynamic forces applied to the pavement are measured with four load cells between the loading frame and the loading rollers.

Vertical pavement deflections generated by the dynamic force are measured with up to four rolling deflection sensors. These sensors consist of a lightweight, rigid, three-wheeled cart supporting a vertically-sensitive velocity transducer (geophone) with a 2-Hz resonant frequency.

The rolling deflection sensors are pulled along with the truck by cables attached to an isolated frame. The rolling sensors can be positioned in any number of configurations. In a normal configuration, three rolling deflection sensors are positioned along a line, so that they are equidistant from the center of the two loaded areas (two loading rollers). The in-line sensor is positioned at the midpoint between the loading rollers, which is a radial distance of 588 mm (1.93 ft) from the center of each loaded area. The first leading sensor is positioned directly in front of the in-line sensor a radial distance of 1524 mm (5 ft) from the center of each loaded area. The second leading sensor is on the same line as the other two sensors a radial distance of 914 mm (3 ft) from the center of each loaded area. Deflections measured with the in-line sensor are a good indicator of the overall stiffness of the pavement system. The outputs of all sensors can be used to determine the shape of the induced deflection basin. The basin shape is a function of the stiffness of the various pavement layers. The deflections measured with the leading sensors provide a very good indication of the load transfer efficiency of joints in rigid pavements.

RDD testing is performed by applying a sinusoidal dynamic force to the pavement while the RDD slowly drives along the pavement. Testing speeds of 0.2 to 0.5 m/s (0.6 to 1.5 ft/sec) are typically used. As the RDD moves over the pavement, the deflections induced by the dynamic force are measured with the rolling sensors. Noise due to the rolling sensor movement over rough pavement surfaces generally occurs at frequencies other than the forcing frequency, and can be eliminated through filtering.

The University of Texas at Austin crew gathers the data. The data is not stored in the TxAPT Web-based Database.

Seismic

There are three seismic measurements that can be performed:

1. Seismic Pavement Analyzer (SPA)
2. Portable Seismic Pavement Analyzer (PSPA)
3. Spectral Analysis of Surface Waves (SASW)

A full-depth measurement is normally performed using the SPA. A measurement made on top of the ACP is normally performed using the PSPA. A measurement made on top of the subgrade is referred to as a Dirt SPA (DSPA).

Seismic: Seismic Pavement Analyzer (SPA)

The Seismic Pavement Analyzer (SPA) is an instrument for monitoring conditions associated with pavement deterioration that was designed and constructed as part of the Strategic Highway Research Program (SHRP) (Baker et al. 1993). The conditions measured by the instrument are voids or loss of support under a rigid pavement; moisture infiltrating asphalt concrete (AC) pavement; fine cracking in pavements; delamination of overlays; and aging of asphalt. These conditions of pavement deterioration are determined by estimating Young's and shear moduli in the pavement, base, and subgrade from the following wave propagation measurements:

1. Impulse echo.
2. Impulse response.
3. Spectral analysis of surface waves.
4. Ultrasonic surface wave.
5. Ultrasonic body wave velocity.

The instrument designed to make these measurements records the pavement response produced by high- and low-frequency pneumatic hammers on five accelerometers and three geophones, over a wide range of distances. Data acquisition, instrument control, and interpretation are computer controlled, with measurements and interpretations reported in both screen and data base formats.

The SPA is a small trailer equipped with eight transducers and two pneumatic hammers. The trailer is towed to the test site, and the hammers and transducers are lowered to the pavement surface. The hammers then strike the pavement, producing vibrations that are picked up by the transducers, which relay the data to a computer onboard the vehicle towing the SPA. The test is almost fully automated and only takes about 1 minute.



Figure 2-3: Seismic Pavement Analyzer (SPA)

The data are analyzed by a computer software program, which then generates a report describing the condition, thickness, and stiffness of the pavement; any defects in the pavement subgrade; and other properties that are directly related to pavement performance.

The device can be used to pinpoint the location of problems in the pavement or subgrade. It can also reveal the severity of a problem, which would help engineers then select the best

maintenance or repair method. In addition, it can be used to test how well a repair or maintenance treatment is working.

Seismic: Portable Seismic Pavement Analyzer (PSPA)

The technology packaged in the Portable Seismic Pavement Analyzer (PSPA) was adapted from a larger version of the system known as the Seismic Pavement Analyzer (SPA). The SPA was developed by Geomeia Research & Development for the Federal Highway Administration's Strategic Highway Research Program (SHRP) to diagnose problems with pavements in early stages. The PSPA is a miniature version of the SPA that is capable of monitoring the quality and thickness of PCC slabs. Three different seismic testing techniques are used: (1) impact echo, (2) ultrasonic body wave, and (3) ultrasonic surface wave. The quality is assessed by estimating the Young's modulus and shear moduli from ultrasonic surface wave and ultrasonic body wave velocities. The thickness is determined from results obtained from the impact echo test. The moduli from the PSPA can be input into existing elastic layer evaluation procedures to determine allowable load carrying capacity of pavements. The US Army Engineer Waterways Experiment Station (WES) developed correlations between PSPA velocities and flexural strength of PCC under contract to the U.S. Air Force. Evaluation results are extremely sensitive to the flexural strength of the PCC layer.

The PSPA consist of a small metal box containing a high-frequency source and two accelerometers. The receivers are connected to a data acquisition system consisting of a portable computer with data acquisition hardware and software. A test sequence requires less than 15 seconds, and the computer automatically outputs the shear modulus, thickness, impact-echo response, and Young's Modulus from the compression wave velocity.



Figure 2-4: Portable Seismic Pavement Analyzer (PSPA)

Seismic: Spectral Analysis of Surface Waves (SASW)

The Spectral Analysis of Surface Waves (SASW) method is a non-intrusive seismic method with which the dispersive characteristics of Rayleigh-type surface waves propagating through a layered material are measured and then used to evaluate the VS profile of the material (Stokoe et al. 2003 and Stokoe et al. 1994). Dispersion in surface-wave velocity arises from changing stiffness properties of the geological layers with depth. For instance, a high-frequency surface wave, which propagates with a short wavelength, only stresses material near the exposed surface

and thus only samples the properties of the shallow, near-surface material. A lower-frequency surface wave, which has a longer wavelength, stresses material to a greater depth and thus samples the properties of both shallower and deeper materials. Spectral analysis is used to separate the waves by frequency and wavelength to determine the experimental (“field”) dispersion curve for the site. An analytical procedure is then used to match theoretically the field dispersion curve with a one-dimensional layered system of varying layer stiffnesses and thicknesses (Joh 1996). The one-dimensional VS profile that generates a dispersion curve which matches the field dispersion curve is presented as the profile at the site.

SASW measurements involve generating surface waves at one point on the ground surface and recording them as they pass by two or more locations, as illustrated in Figure 2-5.

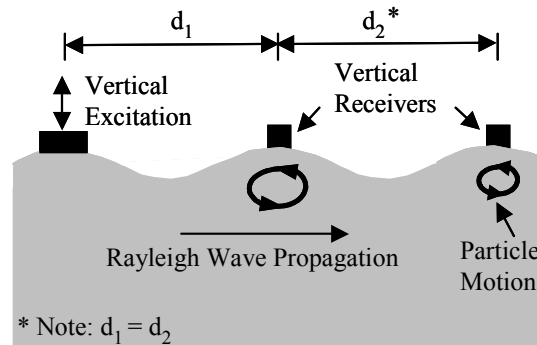


Figure 2-5: Recording surface waves as they pass by two or more locations

All measurement points are arranged along a single radial path from the source. Measurements are performed with several (typically 7 or more) sets of source-receiver spacings. In each set, the distance between the source and first receiver (d_1) is kept equal to the distance between receivers (d_2). The phase shift versus frequency relationship is measured for surface waves propagating between the receivers for each receiver spacing. A typical phase plot is shown in Figure 2-6.

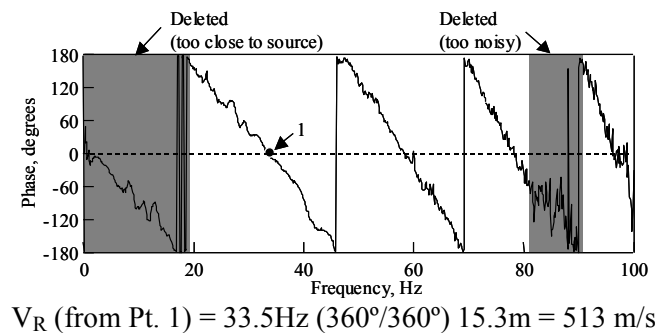


Figure 2-6: Typical phase plot

From each phase plot, the phase velocity of the surface wave is calculated at each frequency knowing the frequency, phase angle (\square) and the distance between the receivers. The result is a plot of phase velocity versus frequency for a given receiver spacing, called an individual dispersion curve.

This procedure is repeated for all source-receiver spacings used at the site and typically involves significant overlapping in the dispersion data between adjacent receiver sets. The individual

dispersion curves from all receiver spacings are combined into a single composite dispersion curve called the experimental or “field” dispersion curve. Once the composite dispersion curve is generated for the site, an iterative forward modeling procedure is used to create a theoretical dispersion curve to match the field curve.

The University of Texas at El Paso crew collects the data. This data is not stored in the TxAPT Web-based Database.

Weather

Weather data is collected every 15 minutes and includes (1) air temperature, (2) Barometric pressure, (3) humidity, (4) radiation, (5) rainfall for the current 15-minute period, (6) rainfall total since midnight, (7) wind direction, and (8) wind speed. This data is automatically gathered by the weather station.

The data cleansing procedures can be:

1. If the date information is year and Julian day then converting Julian day to a month and day.
2. If there is a standard recording period for the data (say every X minutes) then replacing a blank or bad value for date when (a) data is collected every X minutes, (b) the previous data record has a correct date and time, (c) the next data record has a correct date and time, and (d) the next data record is 2*X minutes later than the previous data record.
3. If there is a standard recording period for the data (say every X minutes) then replacing a blank or bad value for time when (a) data is collected every X minutes, (b) the previous data record has a correct date and time, (c) the next data record has a correct date and time, and (d) the next data record is 2*X minutes later than the previous data record.
4. Deleting one hour of data that has duplicate times when the time is set back one hour because of Daylight Savings Time each Fall on the last Sunday in October.
5. Investigate problems when the date and time for the current record is equal or before the date and time for the previous record.
6. Replacing a blank or non-numeric value for air temperature with a number representing a bad measurement such as -999.
7. Replacing a value for air temperature that is below the minimum air temperature ever recorded (-23 degrees for Texas) minus say 10 degrees with a number representing a bad measurement such as -999.
8. Replacing a value for air temperature that is above the maximum air temperature ever recorded (120 degrees for Texas) plus say 10 degrees with a number representing a bad measurement such as -999.
9. Replacing a blank or non-numeric value for Barometric pressure with a number representing a bad measurement such as -999.
10. Replacing a value for Barometric pressure that is below the minimum Barometric pressure value (say 20) with a number representing a bad measurement such as -999.
11. Replacing a value for Barometric pressure that is above the maximum Barometric pressure value (say 31) with a number representing a bad measurement such as -999.

12. Replacing a blank or non-numeric value for humidity with a number representing a bad measurement such as -999.
13. Replacing a value for humidity that is below the minimum humidity value (say 0) with a number representing a bad measurement such as -999.
14. Replacing a value for humidity that is above the maximum humidity value (say 100) with a number representing a bad measurement such as -999.
15. Replacing a blank or non-numeric value for radiation with a number representing a bad measurement such as -999.
16. Replacing a value for radiation that is below the minimum radiation value with a number representing a bad measurement such as -999.
17. Replacing a value for radiation that is above the maximum radiation value with a number representing a bad measurement such as -999.
18. Replacing a blank or non-numeric value for rainfall for the current 15-minute period with a number representing a bad measurement such as -999.
19. Replacing a value for rainfall for the current 15-minute period that is below the minimum rainfall for the current 15-minute period value (say 0.0) with a number representing a bad measurement such as -999.
20. Replacing a value for rainfall for the current 15-minute period that is above the maximum rainfall for the current 15-minute period (say 2.0) with a number representing a bad measurement such as -999.
21. Replacing a blank or non-numeric value for rainfall total since midnight with a number representing a bad measurement such as -999.
22. Replacing a value for rainfall total since midnight that is below the minimum rainfall total since midnight value (say 0.0) with a number representing a bad measurement such as -999.
23. Replacing a value for rainfall total since midnight that is above the maximum rainfall total since midnight (say 20.0) with a number representing a bad measurement such as -999.
24. Replacing a blank or non-numeric value for wind direction with a number representing a bad measurement such as -999.
25. Replacing a value for wind direction that is below the minimum wind direction value (say 0) with a number representing a bad measurement such as -999.
26. Replacing a value for wind direction that is above the maximum wind direction value (say 360) with a number representing a bad measurement such as -999.
27. Replacing a blank or non-numeric value for wind speed with a number representing a bad measurement such as -999.
28. Replacing a value for wind speed that is below the minimum wind speed value (say 0) with a number representing a bad measurement such as -999.
29. Replacing a value for wind speed that is above the maximum wind speed value (say 160) with a number representing a bad measurement such as -999.
30. For the same air temperature sensor, replacing a bad value for air temperature with a number representing a bad measurement such as -999 if a statistical test shows that the value is bad.

31. For the same Barometric pressure sensor, replacing a bad value for Barometric pressure with a number representing a bad measurement such as -999 if a statistical test shows that the value is bad.
32. For the same humidity sensor, replacing a bad value for humidity with a number representing a bad measurement such as -999 if a statistical test shows that the value is bad.
33. For the same radiation sensor, replacing a bad value for radiation with a number representing a bad measurement such as -999 if a statistical test shows that the value is bad.
34. For the same rainfall sensor, replacing a bad value for rainfall with a number representing a bad measurement such as -999 if a statistical test shows that the value is bad.

The site name (Site), date (DateOfTestSD, DateOfTestTX, and DateTimeOfTestGD), time (TimeOfTestST and DateTimeOfTestGD), wind speed (wind_speed), wind direction (wind_direction), air temperature (air_temp), humidity (humidity), radiation (radiation), Barometric pressure (pressure), rainfall for the current 15-minute period (rainfall), and rainfall total since midnight (rainfall24) are stored in the TxAPT Web-based Database in the WeatherData table.

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