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Publication of this paper sponsored by Committee on Monitoring, Evaluation and Data Storage.

Development of a Data Base for Nondestructive Deflection Testing of Pavements

M. Y. SHAHIN, D. D. DAVIS, and S. D. KOHN

ABSTRACT

Currently the U.S. Army is using a pavement management system called PAVER that was developed by the U.S. Army Construction Engineering Research Laboratory (CERL). Along with the Army, the American Public Works Association, the U.S. Navy, and the U.S. Air Force have implemented the management system at several sites. The present system has been developed over several years. The system is centered around a hierarchical data base used to store pertinent information [System 2000 is the data base management system (note that System 2000 is a registered trademark of Intel Corporation)]. Using the data base and interface analysis programs, the user is provided with rapid report generation and analysis of critical information, which allows objective input to the decision-making process. A recent addition to the data base structure is the ability to store nondestructive deflection testing data. The development of the data structure used to store this information and its planned use are described.

Nondestructive testing (NDT) deflection data are an important addition to the PAVER pavement management system for the purpose of pavement design and evaluation and condition prediction. The PAVER system is designed to be a comprehensive management tool (1,2). Therefore, it is imperative that all relevant pavement information for management at both the project and network levels be included. The concept of storing all data in a comprehensive data base structure, where it can be manipulated and processed, is also appealing to the user from an organizational viewpoint.

At the project level NDT data are used for the purposes of pavement evaluation and subsequent restoration, rehabilitation, and resurfacing design. There are several deflection-approach pavement design schemes that require deflection information as input. NDT can also be used to determine in situ material properties of individual layers such as modulus of elasticity (E). This is usually done based on deflection values, layer thicknesses, and using analysis techniques such as elastic layer or finite-element methods. The in situ material properties are used for computing stresses and strains for the selected design vehicle(s), which are in turn used to compute remaining pavement structural life based on past and future traffic.

At the network level NDT data can be used for planning and forecasting. The deflection values, normalized for temperature and time of year, can be assumed to be constant until very near failure. Thus a pavement's deflection, or a derivative function of deflection, can be used as an indicator of pavement strength. This indicator then becomes an independent

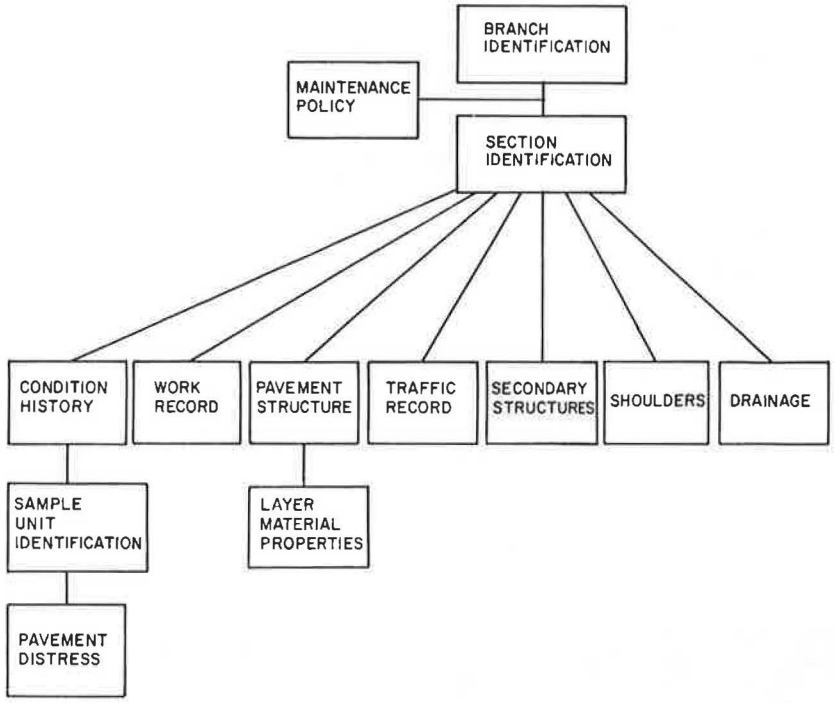

FIGURE 1 Existing PAVER data base logic structure.

variable for predicting pavement performance (3). Also, a sudden increase in deflection values would indicate imminent failure.

In the following sections of this paper the data base structure for the NDT data, its relation to the other data in the PAVER system, and planned use of the NDT data in conjunction with the existing and newly developed pavement analysis programs are described.

NDT DATA BASE STRUCTURE

In order to describe the NDT data structure, it is necessary to describe the overall PAVER data structure. Figure 1 is a conceptual diagram of the existing PAVER data base. Each box shown in the figure is composed of a group of data elements; these groups can be repeated as necessary to store the information on a pavement network. Thus each box is called a repeating group. Within each repeating group, one or more elements called critical elements are defined. The critical elements serve as the unique address identifiers and allow the user to repeat the data group when the critical elements are changed.

The NDT data structure is designed to fit into the existing data base and provide the user with a great deal of flexibility. The new structure consists of the repeating groups shown in Figure 2. (Note that the data groups delineated by dotted lines are from the original PAVER data base.) As an example of the data contained in a repeating group, the elements of the Device ID group are shown in Figure 3. The element marked with the exclamation point (!) is the critical element of this group. Thus each time the Device ID description (Desc) is changed, a new data set can be entered.

The NDT data groups are structured so that they can accommodate analysts who wish to record specific test location data or those who wish to record only summary data. Any level of detail can be stored, depending on the requirements of the engineer. Following is a description of each of the NDT repeating groups.

Device ID

The data elements in the Device ID group will accommodate pertinent information on any NDT testing device in use today and others under development by the U.S. Army Corps of Engineers. Devices in use

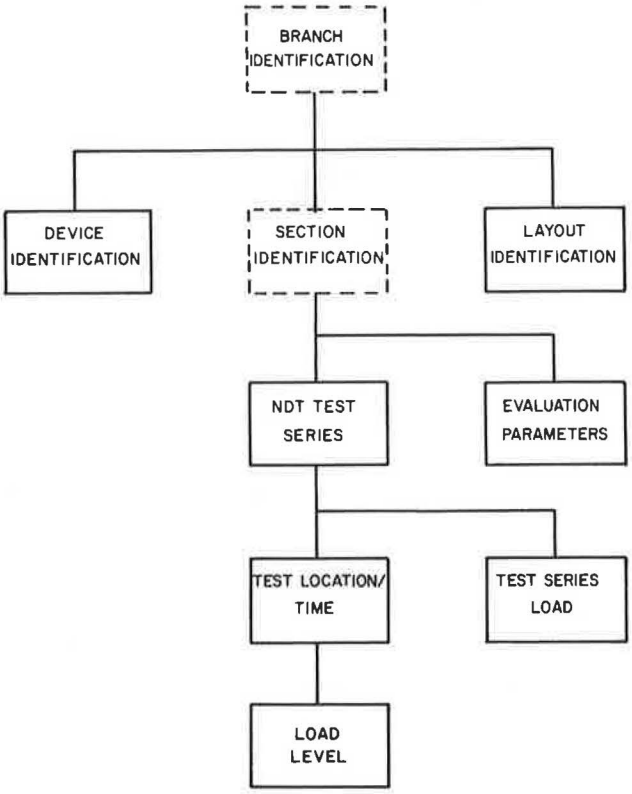

FIGURE 2 NDT data base structure.

```
1200*   DEVICE ID POLICY (RG);
1201*   DEVICE ID DESC (NAME X(5) IN 1200);
1202*   PLATE DIAMETER (DECIMAL NUMBER 9(3).99 IN 1200);
1203*   DIAMETER UNITS (NON-KEY NAME XXX IN 1200);
1204*   NUMBER OF SENSORS (NON-KEY INTEGER NUMBER 99 IN 1200);
1205*   FREQUENCY (DECIMAL NUMBER 9(3).9 IN 1200);
1206*   FREQUENCY UNITS (NON-KEY NAME XXX IN 1200);
1207*   MASS (INTEGER NUMBER 9(6) IN 1200);
1208*   MASS UNITS (NON-KEY NAME XXX IN 1200);
1209*   LOADED AREA (DECIMAL NUMBER 9(6).9 IN 1200);
1210*   AREA UNITS (NON-KEY NAME XXX IN 1200);
1211*   VEHICLE SPEED (INTEGER NUMBER 999 IN 1200);
1212*   SPEED UNITS (NON-KEY NAME X(3) IN 1200);
```

FIGURE 3 Device ID data group.

today can be grouped into three types based on the type of load applied: static, vibratory, and impulse.

The Benkelman beam (4) is an example of a device used for measuring deflection under static loading. The road rater (4) is an example of the vibratory loading type where a sinusoidal force is applied to the pavement through a loading plate. This is usually achieved by applying a dynamic force on a static mass existing on the plate (Figure 4). Therefore, data elements have been defined for storage of plate diameter, mass, and frequency. The falling weight deflectometer (FWD) is an example of the impulse loading type, where a weight is dropped onto a loading plate (Figure 5). The U.S. Army Corps of Engineers and Purdue University have been working on the development of a noncontact NDT deflection and profile measuring system that uses lasers (5) mounted on the side of a load vehicle. For this device, two data elements have been defined for vehicle speed and loaded area.

FIGURE 4 Road rater vibratory load NDT device.

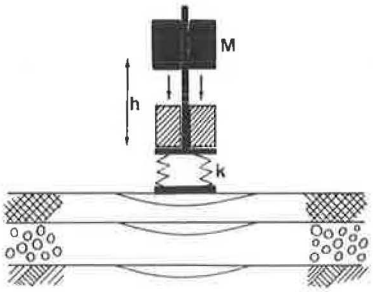

FIGURE 5 Schematic diagram of the FWD.

Sensor Layout ID

The Layout ID group provides detailed information about deflection measuring sensors. Because a particular device may have more than one sensor layout or configuration, a separate repeating group is provided. The Layout ID group has data elements (Sensor Distance and Sensor Offset) to describe the location of up to seven sensors in two dimensions. (Seven is the largest number of sensors available on commercial NDT devices.) This is also a practical limit for characterizing layer material properties based on a deflection basin profile. The Layout ID group also has a data element called Loaded/Unloaded for each sensor. This element is of great significance when testing jointed concrete pavements. It is used to indicate whether a sensor is on the same pavement slab as the load plate. Such information is essential for testing load transfer across transverse and longitudinal joints in concrete pavements.

Several sensor layout patterns may be defined and stored. For example, a typical sensor layout for testing asphalt concrete pavements is a linear arrangement with sensors set at 12-in. intervals, whereas the sensor layout for testing load transfer at a concrete pavement joint may be just two sensors (one each 6 in. from the joint on adjacent slabs).

The position of the Device ID and sensor Layout ID repeating groups in the data base structure allows them to be stored in the most efficient manner. Information on the various devices and sensor layouts used to test all of the pavements in a network needs only be stored once.

NDT Test Series

The NDT Test Series repeating group is used to store summary information for a particular test series. A series is defined as a group of tests on various locations in the pavement section that are considered to be of the same population. This group has average or representative values for a given pavement section.

The data elements in the NDT Test Series group (Figure 6) can be divided into three general subgroups. The first subgroup consists of the basic test series information. The pavement section as well as the device and sensor layout are specified. The NDT Test Series is also identified and described.

Figure 7 is an example of two test series for an asphalt highway pavement section (plan). Figure 8 is an example of four test series for a jointed concrete runway pavement section (plan). The total number of test locations for each series as well as the test interval (average distance between test locations) may also be recorded. Such information provides an indication of the adequacy of coverage of the tests as well as the reliability of the representative values for the test series.

The second subgroup of data elements in the NDT Test Series group consists of representative or mean weather conditions found during testing. The air and pavement temperatures are important for normalizing test deflections recorded in all types of weather

```
3200*   NDT TEST SERIES (RG IN 1000);
3201*  !DEVICE ID (NAME X(5) IN 3200);
3202*  !LAYOUT ID (NAME X(5) IN 3200);
  3203* ! NDT TEST DATE (DATE IN 3200);
  3204* ! TEST SERIES (NAME X(10) IN 3200);
  3205*   TEST SERIES DESCRIPTION (NON-KEY NAME X(15) IN 3200);
  3206*   NUMBER OF TESTS (INTEGER NUMBER 99 IN 3200);
  3207*   TEST INTERVAL (DECIMAL NUMBER 9(4).9 IN 3200);
  3208*   INTERVAL UNITS (NON-KEY NAME XX IN 3200);
  3209*   REP AIR TEMP (DECIMAL NUMBER 9(3).9 IN 3200);
  3210*   TEMP UNITS (NON-KEY NAME X IN 3200);
  3211*   REP PAVEMENT TEMP (DECIMAL NUMBER 9(3).9 IN 3200);
  3212*   TEST COMMENTS (NAME X(44) IN 3200);
  3213*   REP SERIES LOAD (INTEGER NUMBER 9(5) IN 3200);
  3214*   REP SERIES LOAD UNITS (NON-KEY NAME XX IN 3200);
  3215*   REP CORRECTED DSM (INTEGER NUMBER 9(5) IN 3200);
  3216*   DSM UNITS (NON-KEY NAME X(3) IN 3200);
  3217*   REP CORRECTED DSM STD DEV (DECIMAL NUMBER 9999.9 IN 3200);
  3218*   REP CORRECTED LONG LOAD TRANSFER (INTEGER NUMBER 9(3) IN 3200);
  3219*   REP CORRECTED LONG LD TRANS STD DEV
          (NON-KEY DECIMAL NUMBER 9(2).9 IN 3200);
  3220*   REP CORRECTED TRANS LOAD TRANSFER (INTEGER NUMBER 9(3) IN 3200);
  3221*   REP CORRECTED TRANS LD TRANS STD DEV
          (NON-KEY DECIMAL NUMBER 9(2).9 IN 3200);
  3223*   REP BASIN CHARACTERISTIC 1 (DECIMAL NUMBER 9(3).9 IN 3200);
  3224*   REP BASIN CHARACTERISTIC 2 (DECIMAL NUMBER 9(3).9 IN 3200);
  3225*   REP BASIN CHARACTERISTIC 3 (NON-KEY DECIMAL NUMBER 9(3).9 IN 3200);
  3226*   REP BASIN CHARACTERISTIC 4 (NON-KEY DECIMAL NUMBER 9(3).9 IN 3200);
  3227*   REP SERIES DEFL UNITS (NON-KEY NAME XX IN 3200);
  3228*   REP SERIES DEFL 1 (DECIMAL NUMBER 9(3).9 IN 3200);
  3229*   REP SERIES DEFL 2 (DECIMAL NUMBER 9(3).9 IN 3200);
  3230*   REP SERIES DEFL 3 (DECIMAL NUMBER 9(3).9 IN 3200);
  3231*   REP SERIES DEFL 4 (DECIMAL NUMBER 9(3).9 IN 3200);
  3232*   REP SERIES DEFL 5 (DECIMAL NUMBER 9(3).9 IN 3200);
  3233*   REP SERIES DEFL 6 (DECIMAL NUMBER 9(3).9 IN 3200);
  3234*   REP SERIES DEFL 7 (DECIMAL NUMBER 9(3).9 IN 3200);
  3235*   REP SERIES DEFL 1 STD DEV (DECIMAL NUMBER 99.9 IN 3200);
  3250*   TEST-CONCAT (NAME X(38) IN 3200);
```

FIGURE 6 NDT Test Series data group.

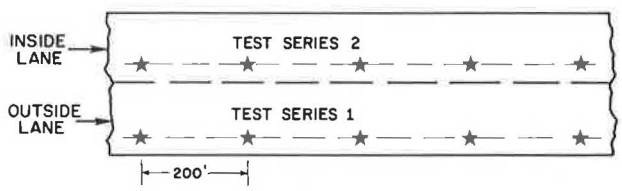

FIGURE 7 Example of test series for a two-lane highway asphalt concrete section.

conditions. Also, the Test Comments data element can be used to record other relevant information.

The third and largest subgroup of data are representative information of the test series in terms of load level, corresponding deflections, and other computed parameters such as the dynamic stiffness modulus (DSM) (6). DSM (Figure 9) is the slope of the straight line portion of load versus deflection and is a required input to the Corps of Engineers airfield and highway pavement evaluation procedures. Load transfer across transverse and longitudinal joints can also be stored. Such data are especially important for design and evaluation of concrete pavements. Data elements are also provided for recording the standard deviation of key section characteristics such as DSM, load transfer, and Sensor 1 deflection. The standard deviations provide valuable information on section variability.

The flexibility of the data base is exemplified further by the four Basin Characteristic elements. These are not specified explicitly, but can be used for such items as deflection basin areas or slopes. Because there are no universally accepted deflection basin parameters, the user is free to choose the ones that prove to be the most useful for his evaluation procedure. Similarly, data elements are provided to store units of measure.

All data elements in the NDT Test Series group can be repeated for each different combination of NDT Test Data and Test Series data elements.

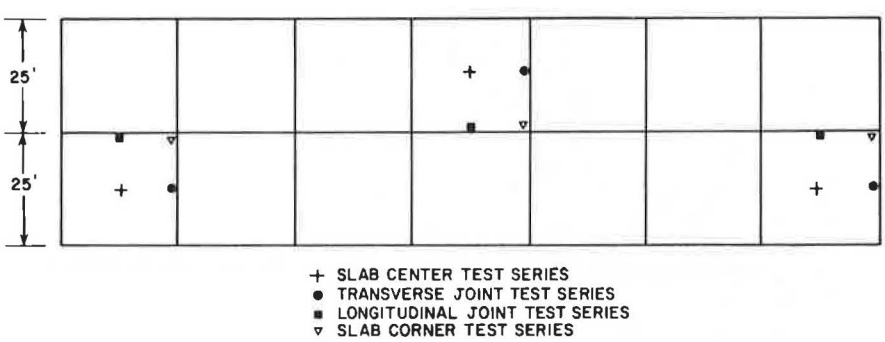

FIGURE 8 Example of test series for jointed portland cement concrete runway pavement section.

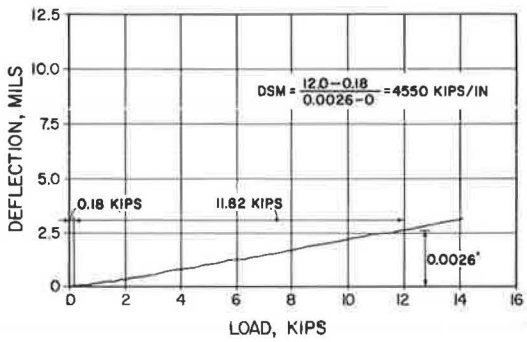

FIGURE 9 Example DSM calculation.

Test Series Load

The Test Series Load group is a subset of the NDT Test Series group. It allows for storage of deflection data for various load levels. Thus an unlimited number of representative series loads and deflections can be stored for future analysis.

Test Location/Time

The Test Location/Time repeating group is also a subset of the NDT Test Series group. It consists of data elements that describe test results for a particular test location and time of testing. The location information consists of the test location station and offset. The Time of Test is a critical data element in this data group. It is used to distinguish between test results of the same location or station but tested at different times. This is important when using a specific test location as a reference point to establish a temperature correction relationship for a given test series. Because the pavement temperature varies over the course of a day, the NDT deflections are also likely to vary, as shown in Figure 10. Thus a temperature-deflection relationship should be established.

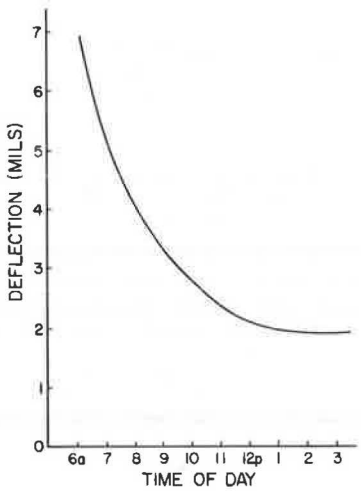

FIGURE 10 Example deflection change with time of day (or temperature) for a concrete slab corner.

The data elements for the Test Location/Time group are shown in Figure 11. Both the air temperature and the pavement surface temperature may be recorded. Parameters computed from deflection data such as DSM, Load Transfer, and Basin Characteristic 1 through 4 may also be stored at this level.

All data elements in the Test Location/Time group can be repeated for each different Time of Test data element.

Load Level

The Load Level repeating group is a subset of the Test Location/Time group and represents the last level in the data base structure. This group consists of the actual test values for a particular load and its resulting deflections. The data elements are shown in Figure 12. Once again, there are seven data elements, labeled Defl 1 through Defl 7, available to record deflection values. Also, at the end of this group there is space for comments.

EVALUATION PARAMETERS DATA GROUP

The Evaluation Parameters data group is a direct subset of Section Identification (i.e., information in this group can be stored regardless of whether NDT data are stored or not). The data elements of this group are shown in Figure 13. The information in this group can be repeated for any different combination of the following data elements: Evaluation Date, Design Vehicle, Design Load, and Design Passes. The group is designed, as for the rest of the PAVER system, for use for both highway and airfield pavements. The following example from an evaluation of a U.S. Army airfield is provided for illustration purposes. For a given pavement section with a design aircraft C141, a design load of 323 kips, and design passes of 20,000, the evaluation parameters given in Table 1 were computed (7). As can be seen in Figure 13, a data element has been defined for the storage of each of the determined evaluation parameters.

```
3300*   TEST LOCATION/TIME (RG IN 3200);
  3301* ! TIME OF TEST (INTEGER NUMBER 9(4) IN 3300);
  3302*   LOCATION-STATION (NAME X(7) IN 3300);
  3303*   LOCATION-OFFSET (NAME X(10) IN 3300);
  3304*   SURFACE TEMPERATURE (NON-KEY DECIMAL NUMBER 9(3).9 IN 3300);
  3305*   AIR TEMPERATURE (NON-KEY DECIMAL NUMBER 9(3).9 IN 3300);
  3306*   DSM (INTEGER NUMBER 9(5) IN 3300);
  3307*   CORRECTED DSM (INTEGER NUMBER 9(5) IN 3300);
  3308*   LONG LOAD TRANSFER (INTEGER NUMBER 9(3) IN 3300);
  3309*   CORRECTED LONG LOAD TRANSFER (INTEGER NUMBER 9(3) IN 3300);
  3310*   TRANS LOAD TRANSFER (INTEGER NUMBER 9(3) IN 3300);
  3311*   CORRECTED TRANS LOAD TRANSFER (INTEGER NUMBER 9(3) IN 3300);
  3312*   BASIN CHARACTERISTIC 1 (DECIMAL NUMBER 9(3).9 IN 3300);
  3313*   BASIN CHARACTERISTIC 2 (DECIMAL NUMBER 9(3).9 IN 3300);
  3314*   BASIN CHARACTERISTIC 3 (NON-KEY DECIMAL NUMBER 9(3).9 IN 3300);
  3315*   BASIN CHARACTERISTIC 4 (NON-KEY DECIMAL NUMBER 9(3).9 IN 3300);
  3316*   LOCATION COMMENTS  (NON-KEY NAME X(40) IN 3300);
  3350*   TESTLOC-CONCAT (NAME X(43) IN 3300);
```

FIGURE 11 Test Location/Time data group.

```
3700*   LOAD LEVEL (RG IN 3300);
  3701* !LOAD (INTEGER NUMBER 9(5) IN 3700);
  3704*  DEFL 1 (DECIMAL NUMBER 9(4).9 IN 3700);
  3705*  DEFL 2 (DECIMAL NUMBER 9(4).9 IN 3700);
  3706*  DEFL 3 (DECIMAL NUMBER 9(4).9 IN 3700);
  3707*  DEFL 4 (DECIMAL NUMBER 9(4).9 IN 3700);
  3708*  DEFL 5 (DECIMAL NUMBER 9(4).9 IN 3700);
  3709*  DEFL 6 (DECIMAL NUMBER 9(4).9 IN 3700);
  3710*  DEFL 7 (DECIMAL NUMBER 9(4).9 IN 3700);
  3712*  LOAD COMMENTS (NAME X(40) IN 3700);
```

FIGURE 12 Load Level data group.

The remaining two data elements in this group are only applicable to airfield pavements. They are provided for the storage of the internationally required evaluation parameters known as the Aircraft Classification Number (ACN) and the Pavement Classification Number (PCN). An FAA circular is being printed that describes the determination of these parameters based on allowable aircraft load (8).

OVERALL PAVER DATA BASE STRUCTURE

The PAVER data base structure, including NDT, is shown in Figure 14. It is shown in an inverted tree structure, with data groups located at levels 0 through 4. The amount of detail increases with the increase in level number. For example, at level 0 an entire street is defined, at level 1 each uniform section of the street is defined, and so forth. This is true as long as the groups are linked. Thus for Drainage, no more details can be stored beyond level 2, whereas for Pavement Structure the Layer Material Properties group can be repeated as desired.

There are three groups that are not associated with the Section Identification group: Device ID, Layout ID, and Maintenance Policy. The information in these groups need not be changed among pavement

TABLE 1 Evaluation Parameters

Parameter	Value
Allowable load for 20,000 passes (kips)	229
Allowable passes for 323 kips	30
Asphalt concrete overlay required for 20,000 passes of 323 kips (in.)	5
Portland cement concrete (in.)	
Fully bonded overlay required	–[a]
Partially bonded overlay required	7
Unbonded overlay required	8

[a]Not evaluated.

```
2800*   EVALUATION PARAMETERS (RG IN 1000);
  2801* ! EVALUATION DATE (DATE IN 2800);
  2802* ! DESIGN VEHICLE (NAME X(8) IN 2800);
  2803* ! DESIGN LOAD (NAME X(6) IN 2800);
  2804* ! DESIGN PASSES (INTEGER NUMBER 9(8) IN 2800);
  2805*   ALLOWABLE LOAD ( INTEGER NUMBER 9(6) IN 2800);
  2806*   ALLOWABLE PASSES ( INTEGER NUMBER 9(8) IN 2800);
  2807*   REMAINING LIFE ( INTEGER NUMBER 99 IN 2800);
  2808*   AC OVERLAY REQUIRED ( DECIMAL NUMBER 99.9 IN 2800);
  2809*   PCC-F OVERLAY REQUIRED ( DECIMAL NUMBER 99.9 IN 2800);
  2810*   PCC-P OVERLAY REQUIRED ( DECIMAL NUMBER 99.9 IN 2800);
  2811*   PCC-U OVERLAY REQUIRED ( DECIMAL NUMBER 99.9 IN 2800);
  2812*  ACN (INTEGER NUMBER 999 IN 2800);
  2813*   PCN (INTEGER NUMBER 999 IN 2800);
  2814*   PCN CODE (NAME X(4) IN 2800);
2825*  EVAL-CONCAT (NAME X(40) IN 2800);
```

FIGURE 13 Evaluation Parameters data group.

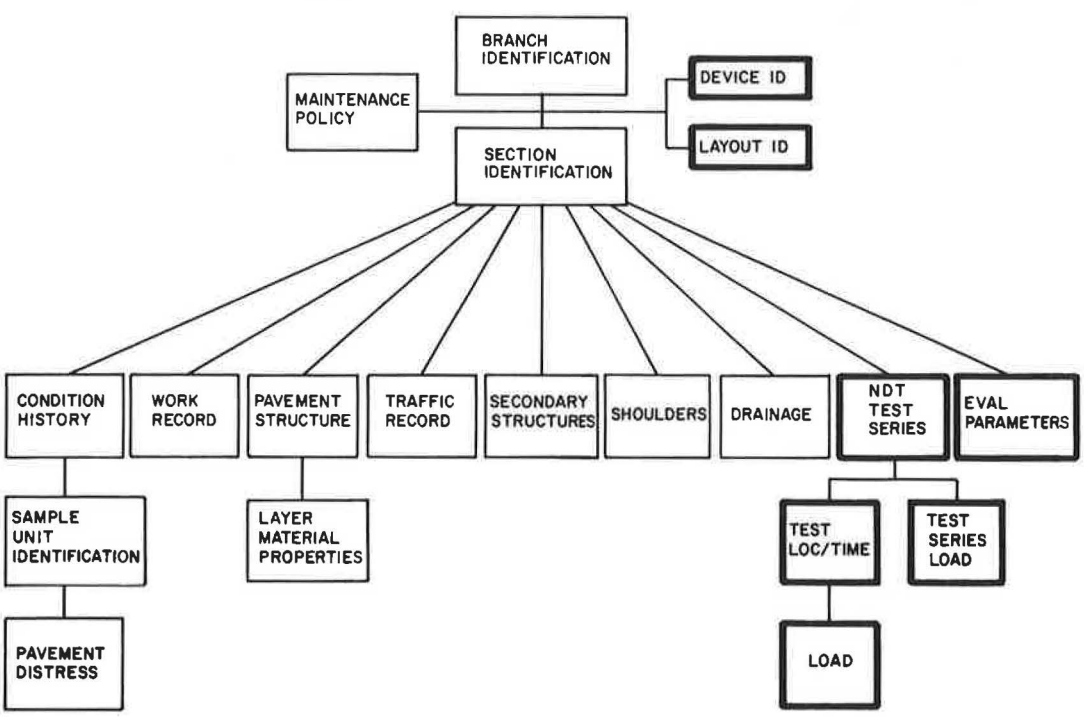

FIGURE 14 New PAVER data base logic structure.

sections; rather it can be used as a reference. Thus the groups are stored under a dummy Branch ID. The groups are also designed so that any number of Device ID or Layout ID groups could be defined.

PLANNED USE OF NDT DATA BASE

The PAVER system is a dynamic system. New developments and improvements are regularly added. Those developments planned that will make use of NDT data include pavement condition forecasting models and pavement structural evaluation routines.

The proposed pavement condition prediction models will be based on the pavement condition index (PCI). PCI is a repeatable index that is a key to the PAVER system. PCI is highly correlated to the level of maintenance required. Thus PCI is an excellent indicator of the amount of money required to maintain a pavement network.

PCI prediction models are based on available relevant variables such as NDT data. These models provide valuable input to both network- and project-level management. At the network level they are used for condition forecasting and budget planning. At the project level they are used to determine the consequence of changes in traffic or the impact of a given maintenance strategy. Structural evaluation and overlay design models that use NDT data are also currently being interfaced with PAVER. Such programs would greatly expedite the calculations required to evaluate every pavement section for several design vehicles. The possible number of design vehicles could be extremely large for airfield pavements.

The planned use of NDT data is not intended to replace the need for qualified pavement engineering expertise, but it will reduce the amount of labor and tedious work involved.

SUMMARY

NDT data groups have been added to the PAVER pavement management system data base. The data were arranged in several repeating groups on four hierarchical levels. The NDT data elements are flexible enough to handle various types of testing devices and patterns. Many levels of data can be stored, from summary network-level information to specific local test information. These data are currently being interfaced with analysis programs for improvement in the evaluation, design, and condition prediction capabilities of the PAVER system.

Although these elements have been designed for the System 2000 data base management system, it is believed that, to have full use of NDT data, a similar set of data elements are needed in any system. (Note that System 2000 is a registered trademark of Intel Corporation.)

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Publication of this paper sponsored by Committee on Monitoring, Evaluation and Data Storage.