Analysis of Trends and Correlations of Historical WisDOT Soil Laboratory Results Through the Development of an Electronic Database

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WisDOT ID No. 0092-11-04
May 2015

Research & Library Unit

Wisconsin Highway Research Program

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Technical Report Documentation Page

1. Report No. WHRP 0092-11-04	2. Government Accession No	3. Recipient's Catalog No
4. Title and Subtitle Analysis of Trends and Correlations of Historical WisDOT Soil Laboratory Results Through the Development of an Electronic Database		5. Report Date May 2015 6. Performing Organization Code
7. Authors Mark S. Meyers, Samuel Owusu-Ababio and Christina J. Curras		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Wisconsin – Platteville Department of Civil and Environmental Engineering 1 University Plaza Platteville, WI 53818		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Wisconsin Department of Transportation Research & Library Unit 4802 Sheboygan Ave. Rm 104 Madison, WI 53707		13. Type of Report and Period Covered Final Report, 2011-2015 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The purpose of this research was to create an electronic database of WisDOT soil laboratory testing results that could be linked to a Geographic Information System (GIS) to allow for searching WisDOT project related records by spatial location, which would facilitate the planning of geotechnical explorations and provide geotechnical data for planning and design of transportation facilities.

17. Key Words	18. Distribution Statement		
Soil tests, databases, Wisconsin Department of Transportation, Wisconsin Highway Research Program	No restriction. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield VA 22161		
18. Security Classif.(of this report) Unclassified	19. Security Classif. (of this page) Unclassified	20. No. of Pages	21. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Final Report
May 31, 2015

Introduction and Purpose

In the future, the Wisconsin Department of Transportation (WisDOT) will continue to design, construct, maintain, and rehabilitate the existing transportation facilities using methodologies similar to those that have been used in the in the past. For much of this work, the underlying soil characteristics at a given project location typically do not change over time, especially in a given project area. Over the years, WisDOT has performed many laboratory tests on soil samples collected for the design and construction of these various transportation facilities located throughout the state. Generally, these laboratory test results are in paper format, which does not allow for easy retrieval of the test data or for an analysis of trends or correlations between records for various locations across the State. As such, there appears to be a large benefit from organizing the laboratory test results and data into an electronic database that can be easily searched and analyzed for use on future WisDOT projects. Development of this database and analysis of the associated trends and correlations will allow future designers to review this past information, which will be very useful during the planning and early design stages, as well as later in the project when developing subsurface investigation programs.

Objectives

The objectives of this project were twofold: (1) To create an electronic database of WisDOT soil laboratory testing results that will be linked to a Geographic Information System (GIS) to allow for searching WisDOT project related records by spatial location; such a tool will facilitate the planning of geotechnical explorations and provide geotechnical data for the planning and design of transportation facilities; and (2): To analyze the data in the database for trends and correlations relating to location, soil type, soil classification, geologic source, index properties, structural design values, etc., and to compare the trends to typical published values for respective soil types.

Project Tasks

The objectives of the project were accomplished based on a work plan consisting of seven primary tasks: Literature Review; Data Collection and Review; Database Design and Development; GIS Design and Linkage to the Database; Provisioning the Database; Analysis of the Collected Data Using the Database; and Reporting.

Task 1: Literature Review

The objective of Task 1 was to identify, collect, review, and synthesize literature to understand existing state and national practices involving soils and geotechnical engineering related database platforms. The database platforms were examined with respect to structure, input and output formats, software and hardware requirements, and data integration issues with non-geotechnical databases such as construction, design, and performance. According to Schmitt and Owusu-Ababio (2007), the major databases for Wisconsin highway pavements include Meta-manager, construction, design, and performance. Meta-Manager is a comprehensive integrated database system for conducting needs and performance analyses for pavements and bridges. It is comprised of independent databases organized by region for all five regions in Wisconsin. Each region consists of one Excel spreadsheet workbook with multiple datasheets, as well as, ArcGIS shape files and ArcInfo GIS coverage files that can be used for geographic analysis. The workbook datasheets include information on base, roadway, unimproved pavement condition, improved pavement condition, safety, pavement treatment scoping, mobility, unimproved bridge condition, and improved bridge condition. The mobility and roadway datasheets contain projected traffic volume data. Both datasheets identify pavement segments using sequence numbers, traffic segment identification numbers, and from-and-to reference points. Other relevant fields include highway number by direction, projected 2-way AADT, and percent trucks for 1, 5, 10, 15, and 20-year periods from a base year.

The construction database consists of Microsoft Excel spreadsheets organized by year with two key files, a design/test log file and a mix design data file. The design/test log file contains more than 2,000 records that show fields representing the highway type (STH, local, CTH, etc.), highway number or letter, surface year, aggregate sources, project location (by descriptive start and end points), county, district, project identification number, contractor, PREfix, test number, and mix type. The mix design data file shows mix design data for more than 2,400 records. The mix design data is organized under fields such as %AC, %VMA, aggregate size distribution in mix, %RAP, Gse, Gsb, Gmm, Gmb, dryback correction, flow, stability, TSR, blows, anti-strip agent, and asphalt cement characteristics (type, source, specific gravity).

The design database is a set of Microsoft Access applications organized by year. Each file has two key tables, namely, *ACOffice* and *ACField*. The A*Coffice* table shows pavement location (rural or urban, district, county, termini by descriptive start and end points), construction style (reconstruction, resurfacing, rehabilitation), contract identification numbers (*contract1, contract2*), project length, pavement surface thickness (*Pvtthick*), milling depth, base type (DGBC, CABC, OGBC2), pavement surface paved over (*Pvdovr*), flexible pavement type, surface year (*pvmntyr*), *mix type denoted by HvMvLv*, case type (Standard, Superpave, SMA, AC Warranty), and design ESAL magnitude. The *ACField* table has show fields representing site identification number (site), sequence number (*Sqno*), beginning reference point (RP), contract identification number *(contract2*), highway name by direction, survey length (Survlen), lane, direction, Asphalt or PCC, set value, measured IRI, and rut depth (Rut) immediately after construction.

The performance database is a Microsoft Access™ application, commonly referred to as the pavement information (PIF) file. It contains pavement inventory and condition data and has various customized forms to facilitate data entry. In addition, it has several tables that summarize the data. The key tables include the descriptive (DESC), pavement distress index (PDI) history file, and International Roughness Index (IRI) data. The descriptive table identifies pavement segments by sequence numbers, county name, county number, district, from-to reference points, from feature, highway number, highway direction, functional class number, national highway system designation, surface year and original construction year. In addition, the table has fields for the segment length, cumulative mileage, and roadbed soil type. The IRI table contains more than 150,000 records representing segments tested between 1980 and 2005. The table lists fields representing the sequence number, inverse year, day-month-year segment was tested, the surface year, surface type, air temperature, average values for IRI, PSI, and Rut. In addition, it lists the speed at which tests were conducted.

The PDI history table has more than 65,000 records. It lists the segment sequence number, inverse year, test day-month-year, surface year, distress type severity and extent for quantifying PDI.

Integration of information from disparate databases such as described above and the proposed soil laboratory testing results database will require that semantic discrepancies within and between databases be identified and alleviated. In addition, key fields must be identified within and across the databases to enable simple or complex queries to be performed in order to relate data residing in the different databases. Common institutional issues involved in the implementation and use of the system will be documented. The literature search will be expedited using electronic search engines.

Geotechnical Engineering Database Systems

Geotechnical data have long been recognized to play a critical role in the design, construction, and maintenance of a wide range of civil infrastructure. Significant amounts of geotechnical data are generated over time and often require the use of some type is database system for their management and dissemination. The purpose of this this section of the literature is to examine the state of practice of geotechnical database management systems with particular attention to system design, software platforms, system requirements, data types, data dissemination, and database maintenance.

Graettinger and Simmons (2003) developed and tested a pilot geotechnical-Geographic Information System (Geo-GIS) for 8 projects that involved 18 bridges across the state of Alabama. Using a base map consisting of Alabama counties, roads, railways, and water bodies, four distinct geotechnical data classes (projects, bridges, foundations, and soil borings) were represented as point features on the map. Each class was characterized by location, scanned information, and attribute data. Location information was represented as longitude and latitude, written description, and station-offsets. Scanned data consisted of archived reports on site investigations, bridge construction details, and subsurface information (soil boring and foundation data). Attribute data were organized as a relational database for information pertaining to the four distinct geotechnical data classes. The attribute data was initially compiled into Excel spreadsheets and then saved as a Dbase IV format prior to incorporating into the GIS. The completed Geo-GIS project was made available on two platforms: desktop (ArcGIS® 8.2) and web-based (ArcIMS®). The total storage requirements for the pilot study were 532.6 megabytes at a total cost of $1,144.

Combellick *et al.* (2001) developed a database for more than 1,500 geotechnical boreholes and 1,500 digital water-well logs for the City of Anchorage, Alaska. The borehole database was created in Microsoft Access® and linked to MapInfo® GIS software through an open database connection. The database was maintained on a desktop computer that generated backups each time the database was modified. A summary of the components of the relational database created in Access is shown in Table 1.

Table 1 Content of Data Tables in Relational Database (Source: Combellick *et al., 2001*)

Table Type	Description	Key field(s)
Reports	Project information (organization, project #, report year, maximum borehole depth, where filed	Project # (linked to borehole)
Borehole	Index data(Division of Geological& Geophysical Surveys (DGGS) ID, project #,hole name, hole type, UTM location, location accuracy, reported elevation, data drilled, total depth, types of data entered); one record per borehole	Project # (linked to Reports), DGGS ID (linked to all other tables)

Lithology	Lithologic logs(DGGS ID, depth to top, depth to bottom, lithologic description, unified soil class); one record per layer	DGGS ID (linked to Borehole)
SPT data	Standard Penetration Test data (DGGS ID, depth to top, depth to bottom, material type, blows/ft, sample diameter, hammer weight, drop distance); one record per test	DGGS ID (linked to Borehole)
Sample Test	Lab analytical data (DGGS ID, depth to top, depth to bottom, unit weight, dry density, moisture content, liquid limit, plastic limit, plasticity index, median grain diameter, % gravel, % fines, % clay); one record per sample	DGGS ID (linked to Borehole)
Water level	Measured water level (DGGS ID, date measured, depth to water, comments); one record per measurement	DGGS ID (linked to Borehole)
Velocity	Seismic velocity (DGGS ID, depth to top of interval, depth to bottom of interval, shear-wave velocity); one record per interval	DGGS ID (linked to Borehole)

Gautreau and Bhandari (2008) developed a geotechnical information database for the Louisiana Department of Transportation and Development (LADOTD). The system consisted of four distinct databases interfaced with a GIS web application. The base map for data display consisted of Louisiana state map showing the road network, parishes, rail roads, parks, and waterways of the state. The system component databases and their characteristics are summarized in Table 2.

Table 2. Database Component Characteristics for the LADOTD Geotechnical System

Database Name	Database Software Type	Database Description
Content Manager	DB2	Contains soil boring logs with latitude and longitude or log-mile details; scanned boring log documents, and other data(project #, construction #, project name, district, parishes, and route)
Structures Master (STRM)	IBM-DB2	Contains information on Project #, project location
Bridge Scour	MS Access	Bridge scour data including location, photos, contour maps, soil boring data
Tracking of Project System (TOPS)	DB2	project information including project #, status(finished, proposed, inactive, under construction)(

The Kentucky geotechnical database system was described by Hopkins *et al.* (2005) as a comprehensive dynamic system developed over several years. The database was constructed using Oracle®8i and consisted of four primary components (landslides, rock slopes, structures, and soil and rock information) and two secondary components (engineering and statistical applications). It resided on a server that connected Kentucky district and central highway offices in a client/server structure. The client/server structure allowed users to perform dynamic data entry, manipulation and retrieval. These operations were facilitated by the creation of numerous graphical user interfaces (GUI) using PowerBuilder®8 software. In addition, the MapObjects® software was employed to help display multiple GIS map layers such as roads, landslides, rock fall sites, geotechnical borings, streams, and boundaries.

Suwanwiwattana *et al*. (2001) described a geotechnical database system developed for the City of Bangkok in Thailand. The main operating system for the database construction was the Red Hat Linux due to its proven stability and security, while the PostgreSQL® was used as the database server software for managing and manipulating soil data. The GRASS 5.0 GIS and remote sensing software was chosen to facilitate graphical modeling, 3D analysis, and PostgreSQL® connection support. The data model design used four groups of relations including general borehole, wash boring, field vane shear test, and cone penetration test relations. To enable internet access of database, Apache web server and PHP Script language were compiled and installed to the server machine.

A web-based geotechnical database management system was developed for Nigerian soils by Okunade (2010). The structure of the Nigerian database was a relational database model written in the MySQL language, an open source relational database management software (Morris, 2003). Jorgensen (2003) indicated that MySQL supports a lot of web sites and appears to be the database of choice for web developers. The server-side administrative interface to the database was provided through the phpMyAdmin® software, which was pre-installed on the web host server with MySQL. The database was further described as a point database, with sample location being geo-referenced through the point's mapping coordinates characterized by longitudes and latitudes of the points.

Carrona (2005) outlined geotechnical data management issues pertaining to design, data collection, manipulation, querying, reporting, interaction with other systems, and dissemination. It was reported that efficient data management systems result in useful, accurate, and maintainable information. Carrona emphasized that usefulness of data must be driven by the needs of the consumer, as well as the querying and reporting tools associated with the database system. In addition, data accuracy must be defined in terms of referential integrity, appropriateness of data types, required fields, calculated fields, valid value fields, ranges of numeric data, attribute tables, and validation rules. Other considerations for an efficient database include Meta data, transparency, and granularity of the data. Meta data describes information about other data, while a transparent database labels both fields and tables without any ambiguity. Granularity deals with the amount of information contained in a field; coarser data structures have more information contained in fewer fields, while finer data structures break up the information into more fields. Electronic data logging must be capable of eliminating the interface of paper to database transcription and, when properly designed, enforces consistency. Although a wide range of tools exist for querying, reporting, and visualizing data, it was reported that most agencies do not take full advantage of their databases. Such agencies tend to focus on a fixed list of reports that need to be generated and the data exploration and analyses process gets curtailed. Cole (2004) concluded that one system will never meet all the needs of an agency. It is therefore, imperative for an efficient database system to have the ability to communicate with other programs and the ability to read and write different file types. Programs can either be written within the system or external to it to perform interactive tasks.

In the development of a web-based GIS geotechnical database for hospital sites, Bonneau (2004) recommended the Manifold Net GIS platform over ESRI ArcIMS. Bonneau cited ease of use and administration, cost, extent of spatial structured query language (SQL) operators for data queries, and web server component as factors influencing the choice of the recommended platform.

Carrona (2006) reported that the trend in the number of formats for geotechnical data dissemination has increased over the years. This trend has consequently made data interchange more challenging. To alleviate the problem, Carrona recommended the use of extensible markup language (XML) because of its broad support, proven structures, and pre-made facilities to handle all geotechnical requirements with built-in validation and expansion capabilities.

Summary and Conclusions. While there are several potential database platforms, a Microsoft Access database platform was selected. Primary reasons for selecting the Microsoft Access database platform included licensure, cost, and communication with other WisDOT data bases: Microsoft Access is already licensed for and used by WisDOT and WisDOT is developing a boring log database using Gint; Gint is a boring log database based on an Access platform.

Task 2: Data Collection and Review

Each of the nine WisDOT Regional offices and the Statewide Geotechnical Engineering Office has paper copies of thousands of laboratory test results that were to be entered into the new database. A research team member travelled to each of these locations, with the exception of the Southeast Regional Office, to scan the laboratory test results and other information for use in provisioning the database. The scanned versions of the test results will reside on a server, allowing design personnel or other database users to review the details of specific laboratory tests, if needed.

Task 3: Database Design and Development

The design and development of a database system involves an understanding of several elements including the overall purpose of the system, data types and formats to be collected and managed, software and hardware requirements, relations with external databases, as well as institutional issues involved in the implementation and use of the system. The Soil Lab Test (SoLAT) database system cannot be treated in isolation. Its potential relationship with other databases is depicted in the framework shown as Figure 1. Soil data is a significant input in almost every aspect of highway infrastructure. Soil information is pertinent in the structural design of pavements. In geometric design, soil/geological data are critical to alignment location. In construction, soil data can dictate equipment selection and construction cost. In maintenance and rehabilitation of pavement structures, soil information provides some clues regarding the appearance of certain pavement distresses and the overall performance of the pavement. Environmental data, such as temperature and rainfall, can provide information on soils that are potentially susceptible to frost and construction problems during construction. Hence, the SoLAT database was developed with consideration of the framework shown in Figure 1. The Federal Highway Administration (FHWA) described two alternatives to data integration including data fusion and interoperable databases (2001). The former combines data from multiple sources into a single database, while the latter relate data from different databases through a series of queries.

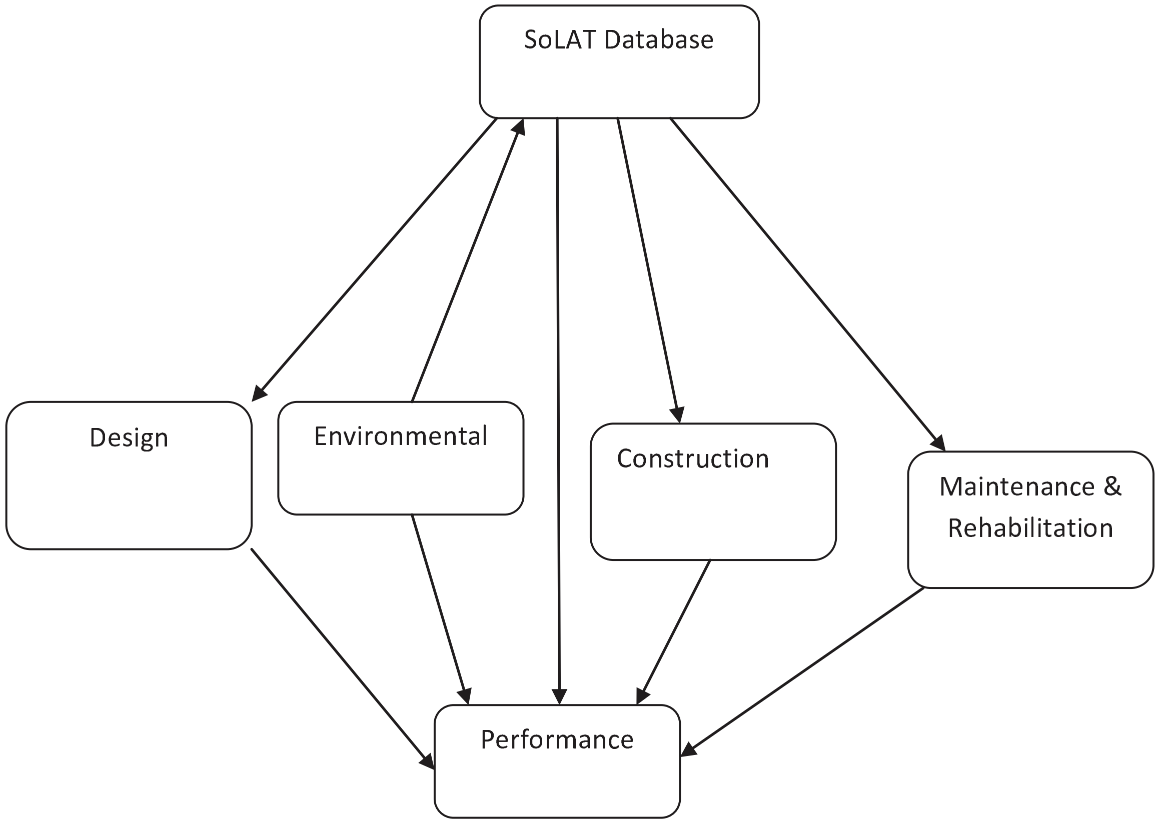


Figure 1: Framework for Database Relationships

Task 4: GIS Design and Linkage to Database

GIS is an information system that is designed to work with data referenced by spatial or geographic coordinates. GIS is an effective tool for integrating data from disparate databases that reside locally or at a remote location. Access to remote databases is made possible through the GIS database connection capabilities.

In GIS, a common data source includes a reference or base map, which enables specific queries about related data tables to be visualized on a dynamic map. The WisDOT Meta-Manager database system has geographic shape files covering the state trunk highway network for all five regions of Wisconsin. According to Javenkoski et al. (2005), these shape files have been produced in accordance with the requirements for the North American Datum of 1983 High Accuracy Reference Network (NAD83 HARN). Hence, geographic files from the Meta-Manager system should be considered potential sources for base maps. Once the base map is established, a soils survey map layer could be overlayed on top of the base map. The Natural Resources Conservation Service (NRCS) produces extensive electronic soil survey maps. Their applicability as the main soil overlay map was explored using *ArcGIS* as the main GIS program. Once all map layers and corresponding attribute key fields compatible with other external databases have been developed, the maps can be linked with the databases. The basic data base architecture is presented in Appendix A.

Task 5: Provisioning the Database

We estimated that approximately 10,000 laboratory test records would need to be entered into the database, with multiple lab test results included in each laboratory test record; in the work completed to date, we estimate that 1.4 GB of data was scanned to PDF files and 36.08 MB of data was provisioned into the database. However, there is no direct relationship between the amount of data scanned to PDF files and the amount of data that was actually entered into the database; much of the PDF file size is information that is not part of the actual database. We estimate that approximately 50 percent of the data that has been scanned has been entered into the database.

Since the data entry did not require graduate level skills, the data was entered into the database using UW-Platteville Civil Engineering students as Research Assistants. Approximately 5 to 10 percent of the records entered into the database were verified to insure proper and accurate entry of the data into the database. Data entry started in the summer of 2011 and continued on a regular basis as long as data was available to provision the database. In late August of 2013, the Access DataBase became unstable; research indicated that the capacity of the database had been exceeded. With a large amount of scanned data yet to be entered into the data base, a decision was made to remove the scanned PDF files (which are large files) from the actual data base and to only enter data into the data base; this solution was successful and the Access Data Base remains stable. The PDF files, as indicated previously, will be placed at another location yet to be determined that will allow access to the scanned test data and analyses.

Task 6: Analysis of the Collected Data Using the Database

Once the data has been entered into the database, Task 6 was to involve the analysis of the collected data to investigate trends and correlations relating to soil types, geologic aspects, classifications, index and structural capacities, etc., including routine and sophisticated levels of test comparisons. The test results were also to be compared to published values for similar soil types and testing. The first area of the state proposed to be analyzed was southeastern Wisconsin. The results of the analysis of the data in this area could have been compared to the results presented in WHRP Report #0092-06-05, where Edil, et al (2009) compared basic laboratory test results with more sophisticated and in-situ test methods on soils in southeastern Wisconsin using WisDOT geotechnical data. Several additional areas of the state can also analyzed, with the results of the analysis being compared to the results presented in WHRP Report #0092-05-08, where Edil, et al (2007) evaluated the effects of physical characteristics and geologic factors on the shear strength of compacted sands from Wisconsin that are used as granular backfill for mechanically stabilized earth walls, reinforced soil slopes, and other transportation structures. The remaining areas of the state to be analyzed are those areas where statistically significant amounts of data are available, such as the Hwy 41 corridor in the Fox Valley.

Since all of the data has not been able to be provisioned, the database is not able to be used in the intended fashion at this time. In lieu of a complete analysis of geotechnical trends across the state, a demonstration of the capabilities of the database is presented through a *Geographic Information System Application of the Database.*

Geographic Information System Application to Database

A geographic information system (GIS) is a tool for capturing, storing, integrating, querying, analyzing, and displaying data sets that have geospatial components. The overall purpose of GIS is to provide the appropriate information pertaining to a project in an easy to understand fashion to facilitate decision-making. GIS was used as a tool in this research to display and perform exploratory data analyses regarding extensive geotechnical information acquired from site and laboratory tests, and stored as a Microsoft Access® database.

The GIS application process involved the following components:

a. Establishment of base/reference map(s) for displaying pertinent information layers
b. Getting access to the geotechnical database
c. Exploratory data analyses of lab test data

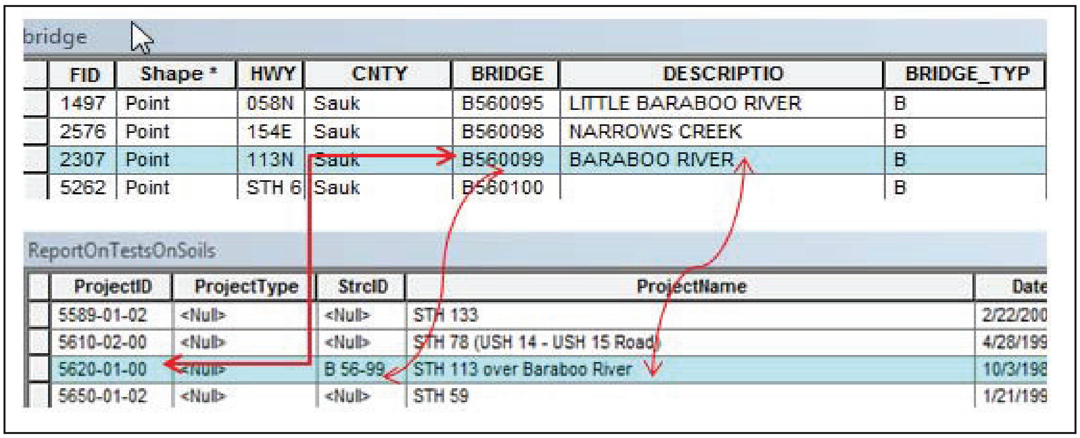
Base/Reference Map and Feature Layer Development

The base map used consisted of an outline of the State of Wisconsin showing individual counties and a network of roads. The map was extracted from a set of bridge inventory GIS files supplied by WisDOT. The coordinate system associated with the base map is the 1927 North American Datum (NAD 27) Transverse Mercator with the detail parameters below:

Projected Coordinate System:	NAD_1927_Transverse_Mercator
Projection:	Transverse_Mercator

False_Easting:	500000.00000000
False_Northing:	-4500000.00000000
Central_Meridian:	-90.00000000
Scale_Factor:	0.99960000
Latitude_Of_Origin:	0.00000000
Linear Unit:	Meter

A preliminary review of the database revealed that the geotechnical database covers a mix of projects pertaining to various infrastructure categories including bridges, airports, roads, culverts, retention ponds, and gabion walls. For these categories and pertinent geotechnical information to be analyzed and displayed in a GIS environment, location information in the form of geographic or projected coordinates about the categories is needed. The database in its present form however, does not contain any coordinate information that can allow infrastructure project information to be displayed in graphical form. An attempt was made to derive coordinate information for the infrastructure category projects found in the database. The procedure involved a closer examination of the WisDOT bridge inventory GIS files, which had coordinate information and brief general descriptions about the infrastructure categories. Whilst the database uses project identification number (PROJECTID) as the key identifier for infrastructure category projects, the WisDOT bridge inventory files with location information use bridge identification number (BRIDGE) to identify specific infrastructure feature or object. Hence, there was no direct link between the database and bridge inventory files when it came to determining which PROJECTID matched a specific "BRIDGE." Using the "ReportOnTestsOnSoils" table from the database and comparing it with the bridge inventory file content, some bridge objects were able to be matched with PROJECTIDs. Figure X.1 shows an example of the matching process where BRIDGE object with ID B560099 was successfully matched with PROJECTID 5620-01-00 based on nearly identical information in both tables. Using the matching process and the GIS software (ArcGIS-ArcMap 10.2.2®), a few bridge and airport related projects were identified and used to create layers that were superimposed on the base map as shown in Figure **X.2**



bridge

FID	Shape *	HWY	CNTY	BRIDGE	DESCRIPTIO	BRIDGE_TYP
1497	Point	058N	Sauk	B560095	LITTLE BARABOO RIVER	B
2576	Point	154E	Sauk	B560098	NARROWS CREEK	B
2307	Point	113N	Sauk	B560099	BARABOO RIVER	B
5262	Point	STH 6	Sauk	B560100		B

ReportOnTestsOnSoils

ProjectID	ProjectType	StrcID	ProjectName	Date
5589-01-02	<Null>	<Null>	STH 133	2/22/200
5610-02-00	<Null>	<Null>	STH 78 (USH 14 - USH 15 Road)	4/28/199
5620-01-00	<Null>	B 56-99	STH 113 over Baraboo River	10/3/198
5650-01-02	<Null>	<Null>	STH 59	1/21/199

Figure X.1 Linkage of Database and Bridge Tables

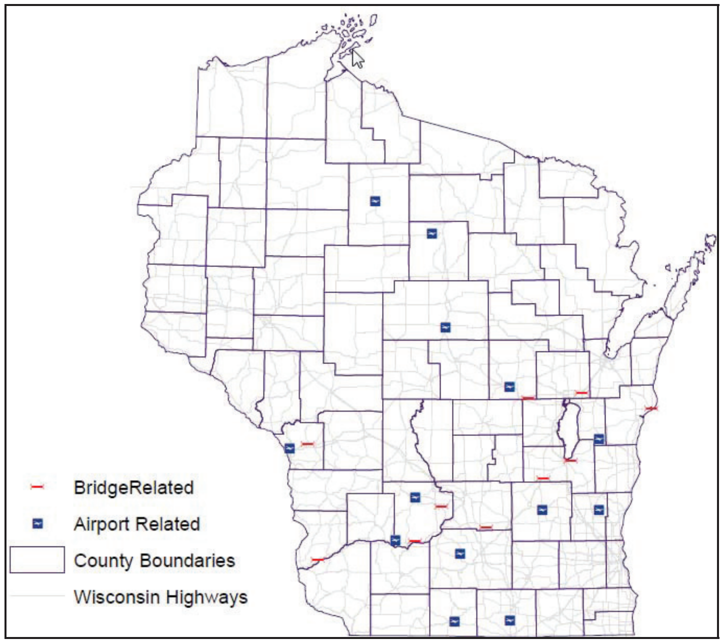


Figure X.2. Bridge and Airport Geotechnical Engineering Project Locations

Accessing the Database from the GIS Environment

With the new layers superimposed on the base map, the next step was to provide a linkage between the geotechnical database and the GIS software platform to enable context specific queries and analyses to be performed regarding the newly created map layers.

The database was developed in a Microsoft Access database format (*.accdb), and was accessed by creating an Object Linking and Embedding Database (OLEDB) connection from ArcGIS-ArcCatalog®. The OLEDB allows accessing data from a variety of sources in a uniform manner; without using OLEDB, ArcGIS cannot directly read or write to the Microsoft Access data format. Figure X.3 shows a successful OLEDB connection to the database tables. Any table of interest can now be added to an ArcGIS-ArcMap® project for desired analyses.

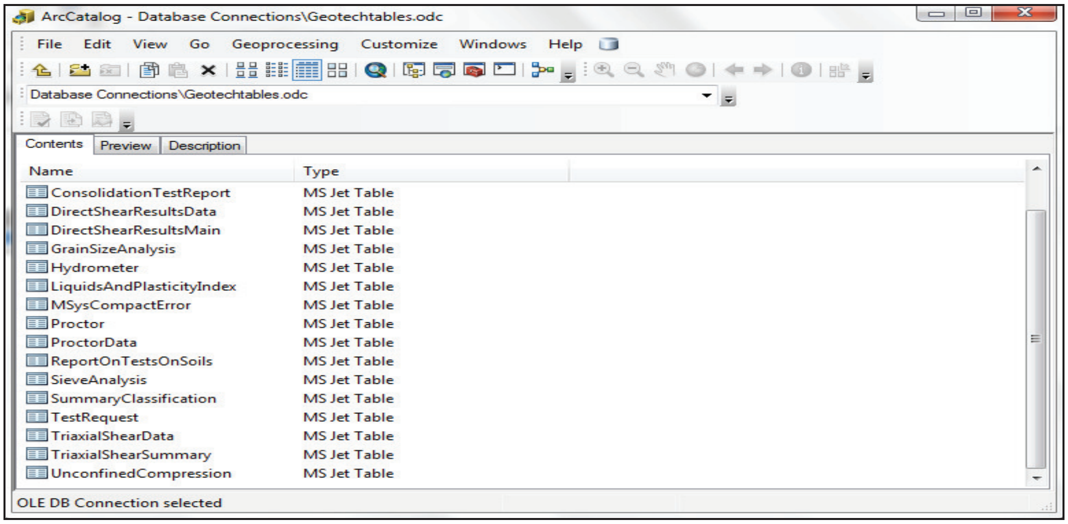


Figure X.3 OLEDB Connection to Geotechnical Database

Exploratory Data Analyses of Geotechnical Data

ArcGIS-ArcMap® has limited statistical analysis capabilities but can be used for simple exploratory analyses of project data. Sample exploratory data analyses were conducted in GIS for specific lab test results pertaining to airport related projects. The analyses focused on two cases; the first case considered analyses that can be performed regarding any single project. The second case involved looking at all airport projects found on the map. The analyses were illustrated by first relating the airport layer to a particular table from the database. In the following analyses, the Proctor data table from the geotechnical database was used.

Proctor Data Analyses for a Specific Project

In Figure X.4, a *scatter plot* of the dry density data from two locations regarding a 2005 project at Dodge county airport indicates that samples from the South side of the project generally had higher dry density values compared to samples from the North side of the project.

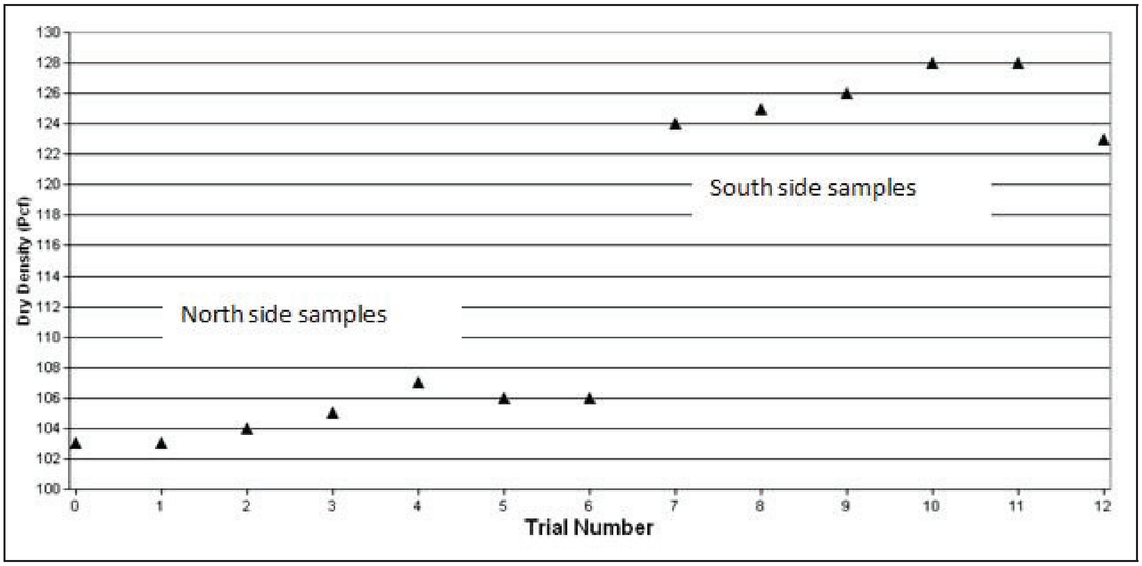


Figure X.4. Scatter Plot of Dry Density Data

2005 Dodge County Airport Project {ProjectID:0617-32-10}

Prior to estimating any statistical summaries for each of the sample clusters, it is worth checking to see if there are any *outliers* that need to be examined or deleted from the dataset. In Figure X.5, Box-and-Whisker plots are used to check for outliers, which if present will lie outside the whisker plot zone and classified as either mild or extreme. Mild and extreme data points will include points that respectively lie at a distance of at least 1.5 and 3 times the interquartile range beyond the box. The vertical line in each box indicates the location of the median value and the plus sign indicates the mean value, which are very close in both cases. A symmetric dataset will have equal length whiskers at both ends of the box but in this case the North side data is skewed to the right or upper end of the dataset, whilst skewed to the left or lower end of the dataset for the South side. There are no outliers in any of the two datasets. In the absence of outliers, basic summary statistics can be computed for the individual datasets as shown in Table X.1.

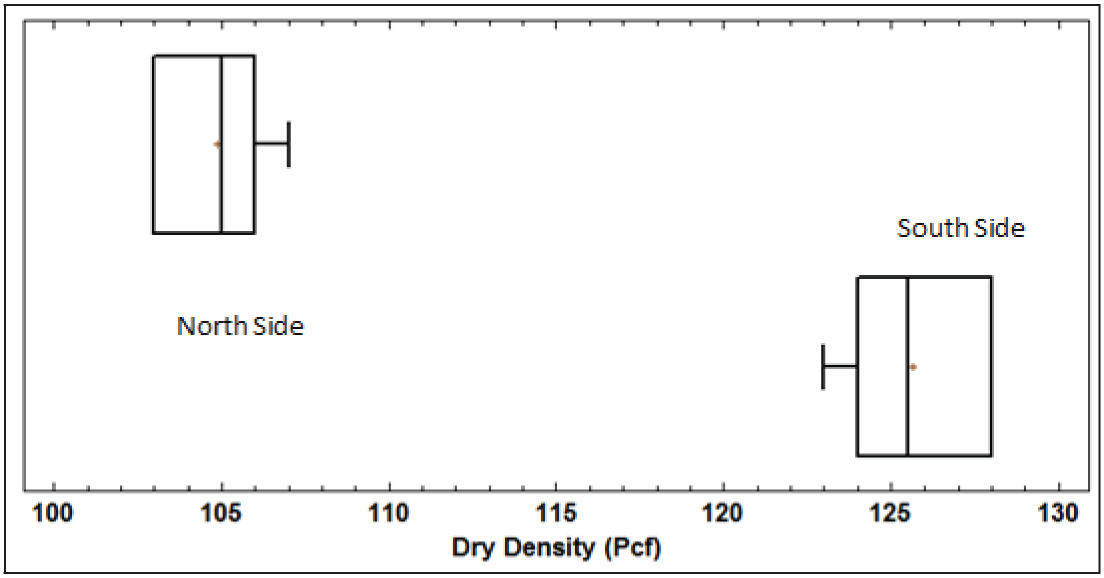


Figure X.5 Box-and-Whisker Plot for Outlier Detection

Table X.1. Basic Summary Statistics for Dry Density data

2005 Dodge County Airport Project

Basic Statistic	Dry Density by Sample Location	
	North side	South side
Minimum, pcf	103	123
Maximum,pcf	107	128

Mean, pcf	104.9	125.7
Standard Deviation,pcf	1.46	1.89
Sample size,n	7	6

Since both datasets are from the same project, it might be of interest to determine if they can be combined and further analyzed as a single dataset. In this case, a *One Way Analysis of Variance* (One-Way ANOVA) may be conducted to check if the means of the two datasets are statistically different. This will require the use of standard statistical software because the GIS software used in this study does not deal with this type of statistical evaluation. The One-Way ANOVA for this example was conducted using Statgraphics® Centurion statistical software. The results are presented as ANOVA plots in Figure X.6 depicting the mean and range containing 95% of the observations for the two sample locations. The non-overlapping means plots suggest that the two sample means are significantly different at the 95% confidence level, and that they need to be treated as two independent samples.

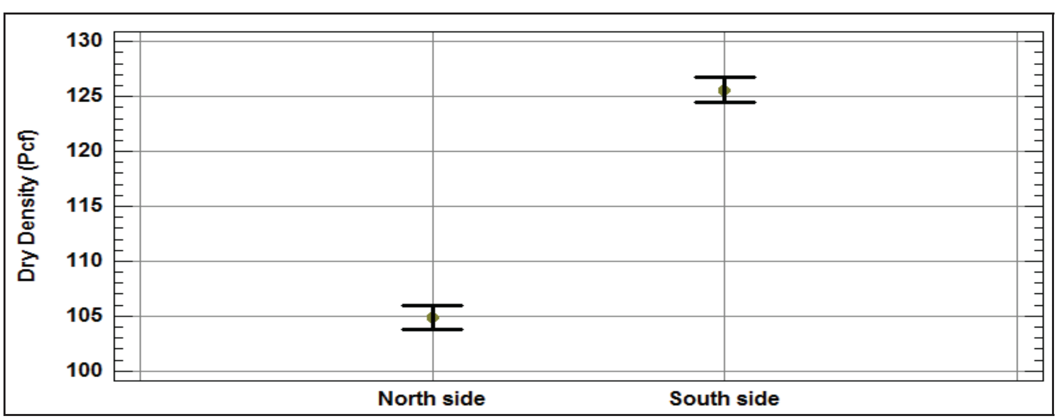


Figure X.6 Mean and 95% Least signigicance Difference Interval Plots

ProjectID:0617-32-10

Once the ANOVA results revealed that each dataset can be treated independently, their relationship with moisture content was examined and plotted as Figure X.7, which shows that the North side dataset with lower densities is characterized by higher moisture contents compared to the South side dataset, which is characterized by high densities with corresponding lower moisture contents.

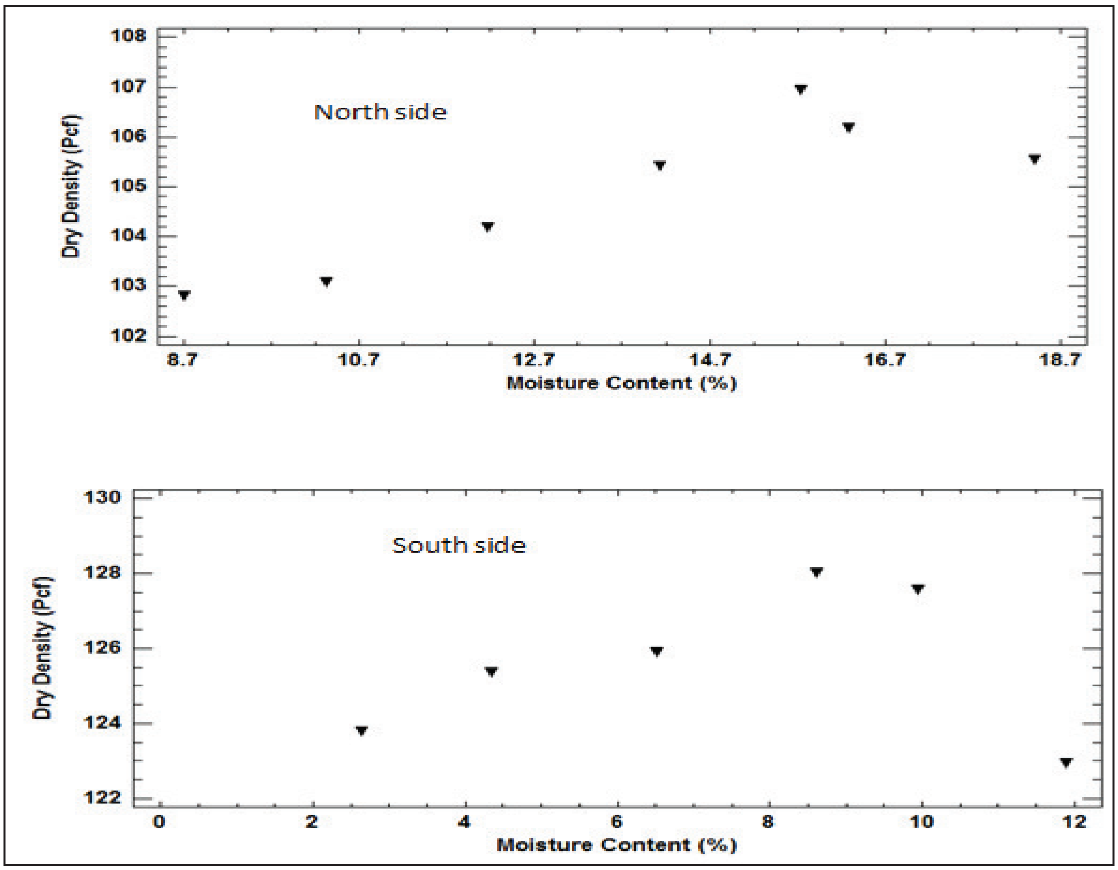


Figure X.7. Dry Density-Moisture Relationship for ProjectID:0617-32-10

X.3.2 Proctor Data Analyses for Multiple Projects

The objective was to examine the general distribution of dry density across multiple projects. In Figures X.8 through X.10, maximum, average, and standard deviation values for dry density are respectively shown for airport related projects. Projects associated with three airports including Tomahawk, West Bend, and Rock County (apron and hanger project) are characterized by higher density values compared to the rest. Such differences may dictate further investigation regarding for example, soil type and moisture characteristics to help explain the differences in the density values. The standard deviation values may be useful in developing dry density specifications for similar projects in the respective areas. For example, the specification may be stated as the Average or Maximum value ± one standard deviation.

Where data are available for projects in the same geographic region (for example within a county), a comparison can also be made to ascertain if dry density requirements for airport projects are significantly different from those for bridge projects. If differences do not exist between projects associated with the two infrastructure categories, then a general dry density specification can be developed and applied to both, allowing for minimum variations for any special case.

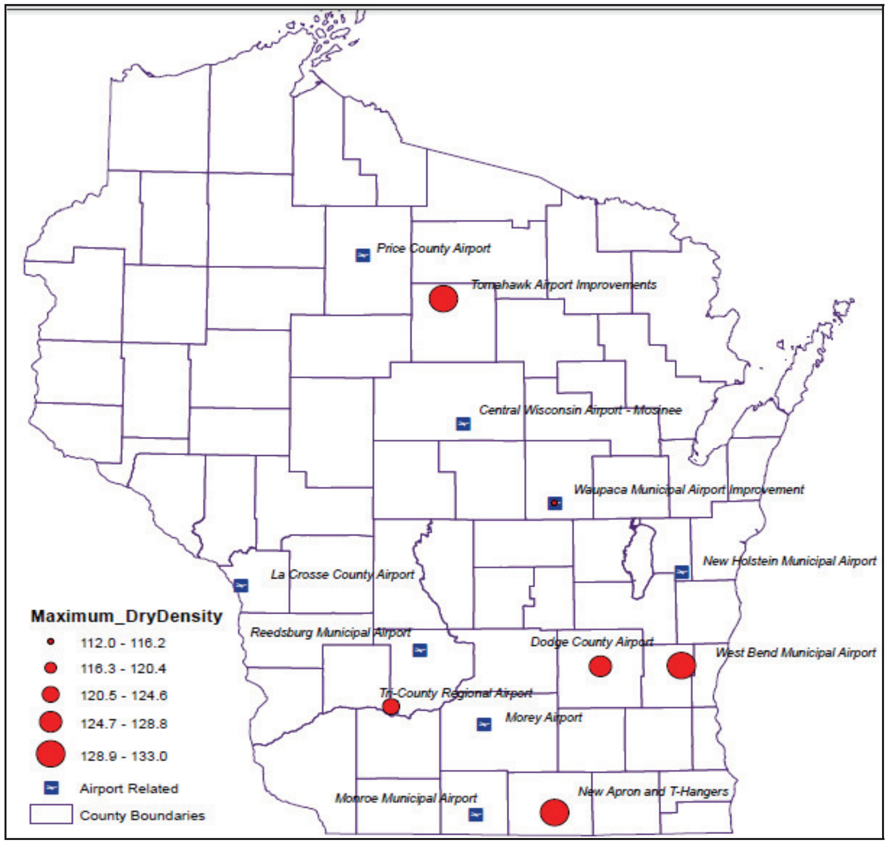


Figure X.8. Maximum Density distribution for airport projects

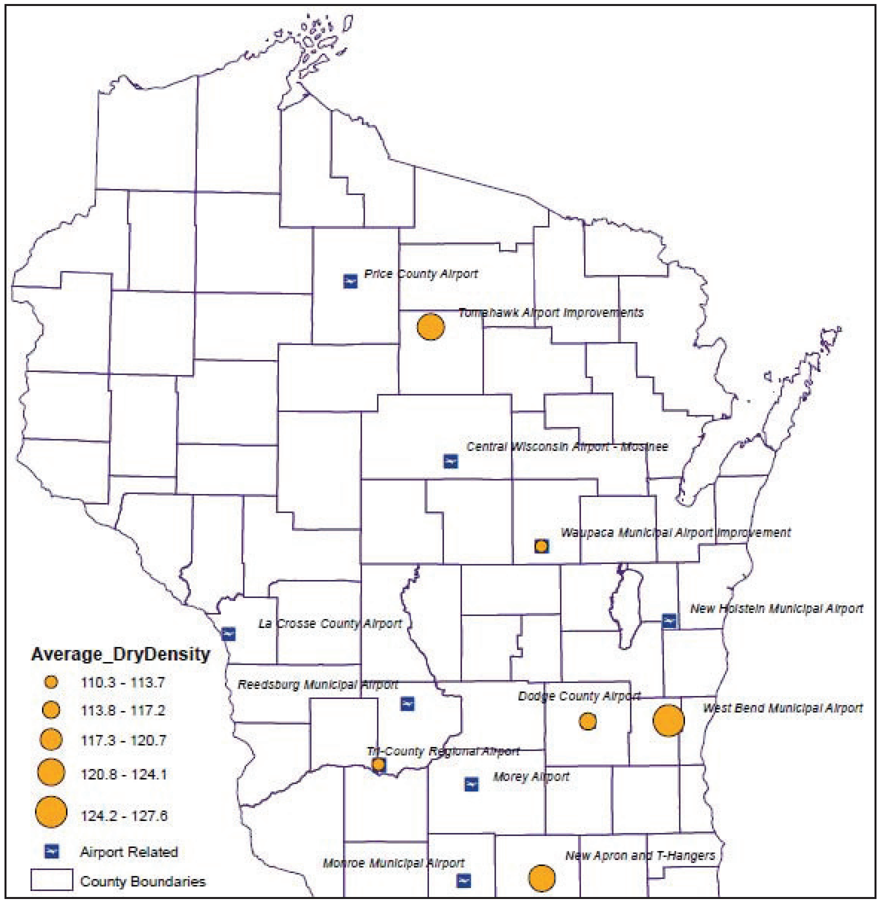


Figure X.9. Average Dry Density Distribution for Airport Projects

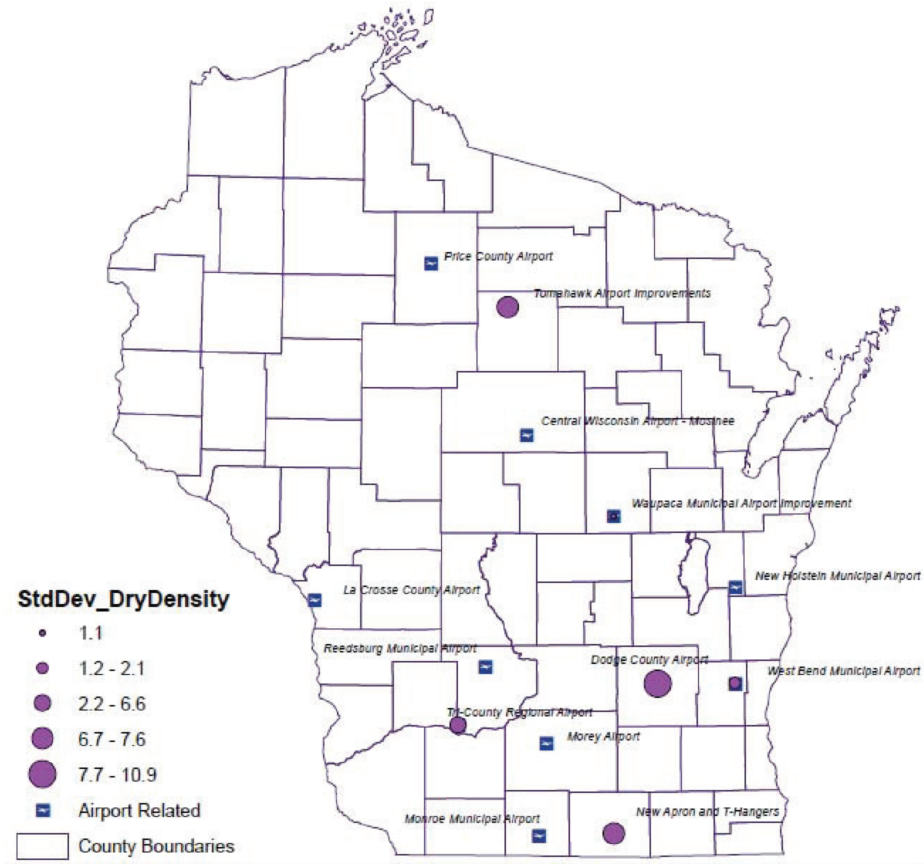


Figure X.10 Dry Density Standard Deviation Profile across Airport Related Projects

Summary and Conclusions

Two map layers pertaining to bridge and airport related projects were developed and superimposed on a state outline base map to facilitate the application of GIS to the geotechnical database. The two map layers were linked to the database through OLEDB connection from ArcGIS-ArcCatalog®. Exploratory data analyses involving proctor data from airport related projects contained in the database were performed for a single project and for multiple projects. The exploratory data analyses conducted can be summarized as in Table X.2.

Table X.2 Exploratory Data Analyses for Airport Project related Geotechnical Information

Analysis Type	Purpose	Project Category	
		Single Project	Multiple Projects
Scatter plots	To detect general behavior or shape of data; relationship between variables	✓	
Box-and-Whisker plots	To detect outliers	✓	
One variable analysis	To calculate basic statistics	✓	
One-Way ANOVA	To compare means of two samples	✓	
Map Symbolization	Depict distribution of data values on map to deduce conclusions		✓

The following observations are made regarding the GIS application to the database:

- The database in its present form does not contain any location information about projects. To take advantage of the full capabilities of a GIS, location information based on some coordinate system or linear referencing along routes would be needed for all projects.
- The database uses project identification number as the key identifier for information search in any database table and also for relating one table to another. To facilitate the

linkage of any database table to the GIS environment, location information for any project must be accompanied by the project identification number.

- The exploratory data analyses were applied to proctor data only but can be extended to other data types in the database.
- For a more complex statistical analysis, specific database tables can easily be exported to any advanced statistical software program.

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Appendix A: Data Base Architecture

Development of Database Architecture

Basic Project Information

- *ProjectID*
- ProjectYear
- Route Type (eg. STH,USH.IH)
- Route NumberDirn (e.g. 94E)
- ProjectStart (e.g. Morgan Rd)
- ProjectEnd (e.g. USH51)
- County
- Region

Basic Boring info

- *ProjectID*
- *Boring# (e.g. 1,2, 586-A)*
- BoringLotionByStation(e.g. 12+34.1 to be entered as 1234.1)
- Boring Offset (e.g. 65'left to be entered as -65 for left and 65 for right)
- BoringLatCoord(e.g.45.8934)
- BoringLongCoord(e.g. -90.1345)
- DepthFrom
- DepthTo
- LabTestRequest (multiple tests possible)
- LabTestRequestBy

Unconfined Compression Test

- *ProjectID*
- *Boring# (e.g. 1,2, 586-A)*
- TestDate
- Test#
- Sample#
- SampleType
- SampleLength
- SampleDescription
- SampleLocationInTube (e.g. BoT,Mid,ToP)
- WaterContent
- WetDensity
- DryDensity
- Saturation
- VoidRatio
- UnconfinedStrength
- UndrainedShearStrength

Consolidation Test

- *ProjectID*
- *Boring# (e.g. 1,2, 586-A)*
- TestDate
- Test#
- Sample#
- SampleDescription
- SampleLocationInTube (e.g. BoT,Mid,ToP)
- WaterContent
- DryDensity
- Saturation
- VoidRatio
- PreConsolPressure
- OverburdenPressure
- CompressionIndex
- CvT90
- CvT50

Mechanical Analysis Test (Atterbergs,GrainSize,SpecificGravity)

- *ProjectID*
- *Boring# (e.g. 1,2, 586-A)*
- TestDate
- Test#
- Sample#
- SampleDescription
- SampleLocationInTube (e.g. BoT,Mid,ToP)
- PlasticLimit
- LiquidLimit
- PlasticityIndex
- SpecificGravity
- PercentPassingSieveSize
- AASHTOClassification
- GroupIndex
- USCS

Unconsolidated Undrained Test

- *ProjectID*
- *Boring# (e.g. 1,2, 586-A)*
- TestDate
- SampleType
- Sample#
- SampleDescription
- WaterContentInitial
- DryDensityInitial
- SaturationInitial
- VoidRatioInitial
- WaterContentAtTest
- DryDensityAtTest
- SaturationAtTest
- VoidRatioAtTest
- FailureStress
- Cell PressureSigma3

Compaction Test

- *ProjectID*
- *Boring# (e.g. 1,2, 586-A)*
- TestDate
- Test#
- Sample#
- SampleDescription
- CompactionTestDesignation (e.g. AASHTO T-99)
- CompactionMethod e.g. "A"
- MoistureContent
- DryDensity