Research Report
KTC-03-07/SPR-176-98-1F

KENTUCKY TRANSPORTATION CENTER

College of Engineering

DEVELOPMENT OF A STATEWIDE INVENTORY PROGRAM

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Research Report KTC-03-07/SPR-176-98-1F

Development of a Statewide Landslide Inventory Program

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College of Engineering
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in cooperation with the
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<tr><td colspan="3">16. Abstract
Development of a comprehensive geotechnical database for risk management of highway landslide problems is described. Computer software selected to program the client/server application in a data window, components and structure of the geotechnical database, and some of the primary factors considered in constructing the database are discussed. In the establishment of a large database that will be used widely, it is extremely important to select development software that will allow simultaneous use of the database by numerous users. Major integrated components of the database include landslide, rock slope, and soil and rock engineering data. This report mainly focuses on the landslide component. The landslide database module provides programmed procedures for gathering field data and rating the severity of landslides. Secondary components of the database include statistical analyzers and engineering applications for performing “on-line” analysis of data, developing correlation between different soil parameters, and performing engineering analysis and designs. Procedures for entering historical soil and rock engineering data have been developed. Procedures for entering and retrieval of landslide and rock slope data have been developed. Methods for “capturing” geotechnical data in a “real-time” mode, which will allow the storage of geotechnical data as it is generated, are currently being programmed. Issues concerning database security, engineering units, and storing and displaying maps, graphics, and photographs are discussed. The database contains procedures for dynamically overlaying the locations of landslides, rock slopes, and borings onto embedded roadway and digitized geological maps. Latitudes and longitudes of rock slopes and landslides were determined using Global Positioning System equipment (sub-meter accuracy). Strategies and illustrations of graphical user interfaces for data entry and retrieval are discussed. Some 1,400 highway landslides were identified and rated using a simple system devised by the University of Kentucky Transportation Center and the Kentucky Transportation Cabinet.</td></tr>
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EXECUTIVE SUMMARY

As highways in Kentucky continue to age, embankments and rock cut slopes deteriorate and frequently collapse. Highway rock slopes, which have been exposed to rain and snow, many cycles of freezing and thawing, extreme differences in temperature, and natural chemical reactions, weather over time and frequently produce rock falls that are hazards to the traveling public. Engineers of the Kentucky Transportation Cabinet identified maintenance and correction of landslides and highway rock slopes as major engineering problems that involve considerable expenditures (millions of dollars) of funds each year. The Federal Highway Administration (FHWA) has strongly suggested to all states that landslide and rock slope inventories be developed so cost estimates and, eventually, remedial plans may be developed.

The actual numbers of landslides and hazardous rock slopes existing on highways under the jurisdiction of the Kentucky Transportation Cabinet were unknown prior to these studies Based on data collected during this study, about 1,400 landslides were identified, documented, and photographed. Attributes of each landslide were noted. The purpose of this study, which was performed at the same time as the rock slope inventory, was to inventory landslides, note their attributes, and provide a priority list of sites that potentially may need repairs, or some type of remedial mitigations, to develop a management system. Slightly more than fifty percent of the landslide sites (about 720) cases, railroad rails, either driven or drilled and anchored into bedrock, were used in attempt to form a retaining structure to resist the landslide movement. Frequently, this method failed to halt the landslide mainly because the sliding mass too large, or the rail piling was not anchored into bedrock. Rail retaining walls oftentimes did not work when the embankment exceeded about twenty feet in height. An inventory of potentially hazardous rock slope sites and a management system has been described elsewhere in a companion report.

As a means of establishing a comprehensive system for managing landslide and rock slope problems in Kentucky, a geotechnical database was developed and is described herein. This database resides on a computer server of the Kentucky Transportation Cabinet. The computer program was developed as a client-server application in a Windows format. The Kentucky geotechnical database was constructed using Oracle®8i (and 9i) database software. This is the standard database software used by the Kentucky Transportation Cabinet. PowerBuilder® software was used to build graphical user interfaces (GUI). The graphical user interfaces allow users to interact with the database stored on a production server of the Kentucky Transportation Cabinet. Rock slope attributes, including preliminary rating categories and numerical ratings, are stored in the database. Landslide attributes, including severity ratings devised by the University of Transportation Center and the Kentucky Transportation Cabinet, are stored in the database. Additionally, latitudes and longitudes of rock slopes and landslides, obtained from Global Positioning System (GPS) equipment (sub meter accuracy) and photographs are stored in the database.

All twelve Highway District Offices and several Central Offices (in Frankfort) of the Kentucky Transportation Cabinet are connected to the database and server. Hence, authorized district and central office personnel can interact with the database. Personnel can easily recall and view the photographs in the database and the attributes of all rock slopes and landslides. Although the database contains several components, this report mainly focuses on the landslide portion of the database. The rock slope and landslide segments of the geotechnical database establish a priority program for allocating and funding repairs of rock fall and landslide sites that are the responsibility of the Kentucky Transportation Cabinet. Information in the database is being used in the development of the Cabinet's six-year plan. By using MapObjects® software and locations from GPS equipment, data site distribution can be viewed on different types of Kentucky maps. Any number of authorized users can log onto the database simultaneously from the twelve highway districts and central office locations. This feature is very useful since different users of the database located in different locations of the state can view the same data at the same time. For example, a user(s) in a central office(s)of Frankfort could view photographs of a rock slope, or landslide, while other users at different locations in the state can view the same photographs at the same time. While viewing the same site photographs at the same time, the users could discuss via telephone important remedial actions that may be needed at a site. Hence, this feature could decrease travel time of central office geotechnical engineering personnel, make better use of their geotechnical expertise, and increase their efficiency.

This report and the inventory of landslides performed on Kentucky's highways and described herein is a response to a suggestion by FHWA. These efforts represent the first major step in attempting to correct landslide and rockfall problems in Kentucky. To develop an effective management plan requires identifying and developing information of landslide and rock fall sites where future corrections and reconstruction may be needed to improve safety and to maintain, or, increase the traffic capacities of roadways. An inventory was performed using the ODOT rock fall hazard rating system of rock slope problem sites on all interstates, parkways, primary routes and several secondary routes in Kentucky. An inventory and rating of landslide sites were performed concurrently with the rock slope inventory. Rating of landslides used a system devised by the University of Kentucky Transportation Center and the Kentucky Transportation Cabinet. Details of the rockfall inventory are the subject of a companion report.

As shown by a limited number of examples cited herein, the cost of repairing, or applying mitigation measures, can be large. Remedial measures for a site may range from a few thousands of dollars to amounts exceeding several million dollars. Although the exact money needed to repair the large number landslides identified herein and stored in the database is unknown at this time, the amount is believed to be very large and may well exceed 200 million dollars. The amount could be as large as 400 million dollars. At this stage, however, it is very difficult to affix exact amounts. The costs of correcting the large number of landslides identified in these studies may well exceed 100 to 200 million dollars. Again these are very approximate estimates. Nevertheless, the amount of money needed in the future will probably require federal assistance in addressing these problems. Consequently, it is suggested that the Kentucky Transportation Cabinet may want to combine their efforts with other states in the nation to seek federal assistance in addressing these problems. It should be noted that some federal assistance is provided in reconstruction projects.

In summary, inventories of landslide and rock slope sites, as reported herein and in a companion report, and building a Windows database, provide the first steps toward developing an effective management plan to began correcting landslide and rock slope problems in Kentucky. Field data describing attributes of each site and hazardous, or severity, ratings have been collected. The data also includes photographs and latitudes and longitudes of each site. Priority listings of the more troublesome rock slope and landslide sites have been developed. To achieve maximum benefits of the management system, it is recommended that the rock slope and landslide portions of the database be fully implemented. This means that it very desirable that district engineers and operations' engineers and personnel start entering essential data into the Kentucky Geotechnical Database. For instance, when a rock fall occurs at a site, field personnel need to enter this fact and include the cost of cleanup, any road closures, fatalities, or injuries, date of occurrence, and any other pertinent information. When any type of maintenance, or remedial mitigation, is performed at a site, this information should be added to the database. Similarly, when maintenance is performed at a landslide site, this information should be added to the database. For example, if rail piles have been added to the site, then this information, including costs and date of repairs should be added to the database. When a roadway is patched, the date and cost should be entered into the database. Patching a roadway in a landslide area more than 2 or 3 times may indicate that the landslide is continuing to move.

In addition to fully implementing the management systems built into the database, the next phase of addressing rock slope and landslide problems may involve development of preliminary plans so that cost estimates may be made. Basically, the first step in this process will involve obtaining cross sections of the slopes so that rock fall analyses may be performed. In estimating the type of remedial plan, or mitigation measure(s), to apply at a selected site, it is recommended that the Colorado Rock Fall Simulation program be used, when appropriate. In obtaining preliminary cross sections for performing the rock fall computer simulation calculations, it is recommended that new laser technology be considered. At least two approaches are available. In the first approach, a "laser" gun may be attached to a GPS unit and used to obtain an "open-face" geological log and profile of the rock slope. The user can usually position the laser gun and GPS unit at one location and point the laser at geological boundaries on the slope. A profile(s) of a slope may be obtained quickly using this approach. In certain instances, the profile may have to be obtained when foliage is not present. In the second approach, new 3-dimensional laser technology can be used to scan, or map, the entire slope in a reasonable time. After scanning, individual (2-dimensional) cross sections may be obtained for analysis. After obtaining a profile, the rock fall computer simulation runs would be performed to estimate the best remedial scheme and costs. Cross sections of the rock slope, computer results, and estimated repair methods and costs can be stored in the Kentucky Geotechnical Database for future reference. Considering the large numbers of potentially hazardous rock slopes and landslides identified in the inventories, and the large costs normally involved in repairing a single landslide, or rock slope problem, several millions of dollars will be required to correct those problems.

INTRODUCTION

Most highways in Kentucky are more than four decades old, and as they continue to age, highway embankments and rock cut slopes deteriorate and frequently collapse, as illustrated in Figures 1 and 2. As noted by Bjerrum (1967), Skempton (1964), and Hopkins, et al. (1975, 1988), many factors cause landslides. Well-known causes include the erosion of the toe of the embankments which removes support, the gradual intrusion of water into the embankment which increases forces tending to move the embankment downslide and a lowering of the available shear strength to resist the pull of gravity, and rapid drawdown of streams which occurs during flooding (Hopkins 1968, 1985, and 1986; Hopkins, et al. 1975). Embankments constructed more than four decades ago were oftentimes built at steep slope angles. Steep slopes promote the gradual reduction in the shear strength available to resist failure and cause instability.

Figure 1. Highway embankment failure on KY 847 in Owsley County.

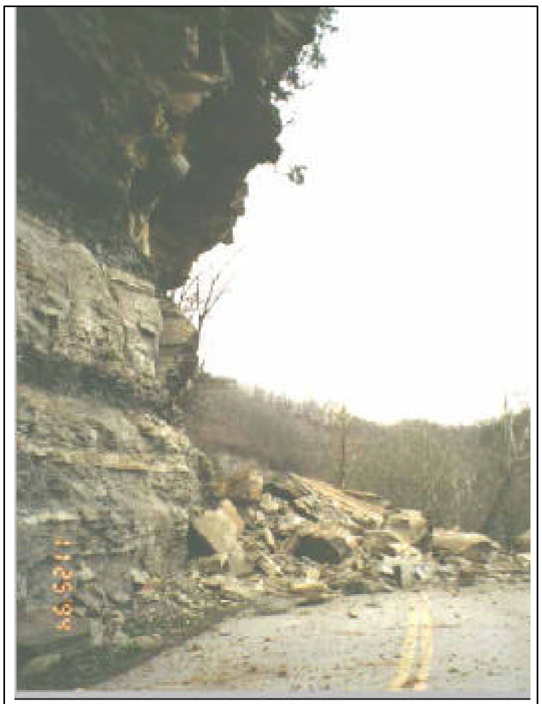


Figure 2. Massive rock fall on KY 1098 in Breathitt County.

In many instances, past shale compaction specifications were inadequate to prevent excessive embankment settlement and instability, as illustrated in Figure 3 (Hopkins and Gilpin 1981; Hopkins and Deen 1983; Hopkins 1988 et al.; and Hopkins and Beckham 1998, 2000). Because of poor compaction of shales, numerous embankment landslides developed on Interstate 75 (Lexington, Kentucky to Cincinnati, Ohio) and Interstate 71 (Louisville, Kentucky to Cincinnati, Ohio), as depicted in Figure 3. Because the shales in the geologic units (Kope and Fairview) appear very firm, and rock-like, when initially excavated, they were compacted in thick lifts (36 inches), which created large voids in the embankment. As water intruded into the embankment, the shales degraded into soil and caused large settlements and finally instability. More than 200 million dollars has been spent over the past four decades repairing the embankments on the two stretches of I 75 and I 71. The repairs averaged about 2 million dollars per mile. Berms were used to repair most of the embankments. Shale specifications developed in the past two decades (Hopkins and Beckham 1998) specified using 12-inch lifts and breaking the shales down into soil-like materials using extra heavy compactors. This technique has been used extensively in recent years. For example, the new shale specifications were used to compact the embankments of the Alexandria-Ashland (now Ky 8) highway in Northern Kentucky. The embankments on this highway were constructed with the same type of shales

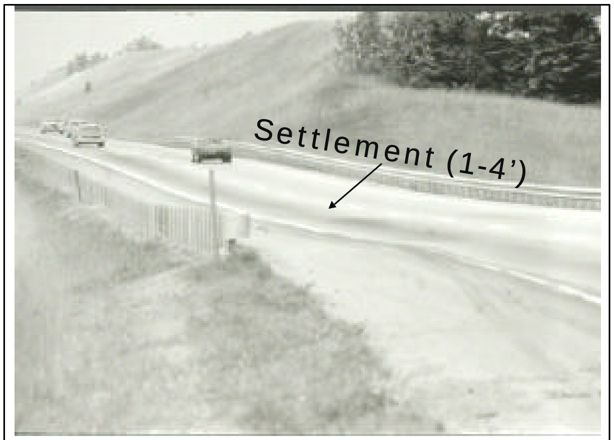


Figure 3. Typical example of large embankment settlement on I 75 about two decades after construction in Northern Kentucky *(after Hopkins and Beckham, 1998).*

(Kope Geologic Formation), or shales of a similar nature (Crab Orchard Geologic Formation), that were used to construct the I-71 and I-75 embankments. Embankment failures on Ky 8 (AA) are almost non-existent. If the behavior of embankments on Ky 8 had followed the behavior of I 75 and I 71 embankments, then repair costs would have exceeded 150 million dollars. Adoption and application of the changed shale compaction specifications have saved the Cabinet millions of dollars. Long-term observations of embankments constructed using the changed shale compaction specifications have shown excellent performance. The embankments have generally been very stable and settlements are very small (Hopkins and Beckham, 1998).

Embankment landslides and cut slope failures in soils and rock in Kentucky have been extensive and expensive. Although weak embankment materials has frequently been involved in creating the failure, many landslides have occurred when the embankment is constructed on weak foundations soils and clayey shales. Failure oftentimes occurs along the shale rock-soil interface. For example, the massive embankment failure shown in Figure 4 occurred in 1973 near Owingsville, Kentucky about four years after construction (Hopkins an Allen 1973). This failure occurred because of a gradual rising of the water table into the embankment and weak, weathered residual clayey shales and soil. When the failure occurred two lanes of Interstate 64 were destroyed. Fortunately, the large movements of the slide were monitored with slope inclinometers and fatalities were avoided after the failure. A large berm and decreased slope angle, Figure 5, was used to repair the embankment failure at a cost $430,000. Today, this cost would be more than 1.5 million dollars.

Figure 4. Large embankment failure on I 64 near Owingsville, Kentucky and MP 118, 1973.

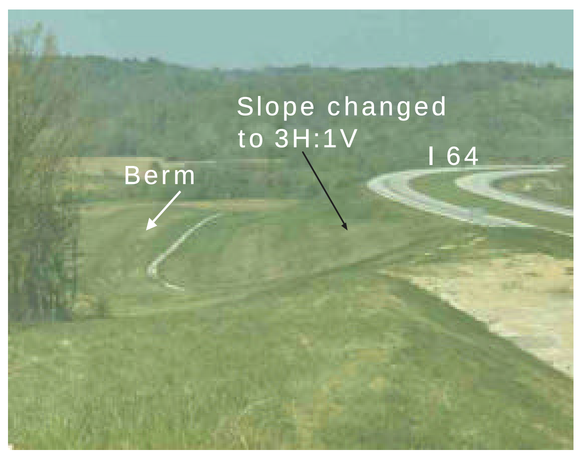


Figure 5. View of berm used to repair I-64 embankment failure (after Hopkins and Allen 1973).

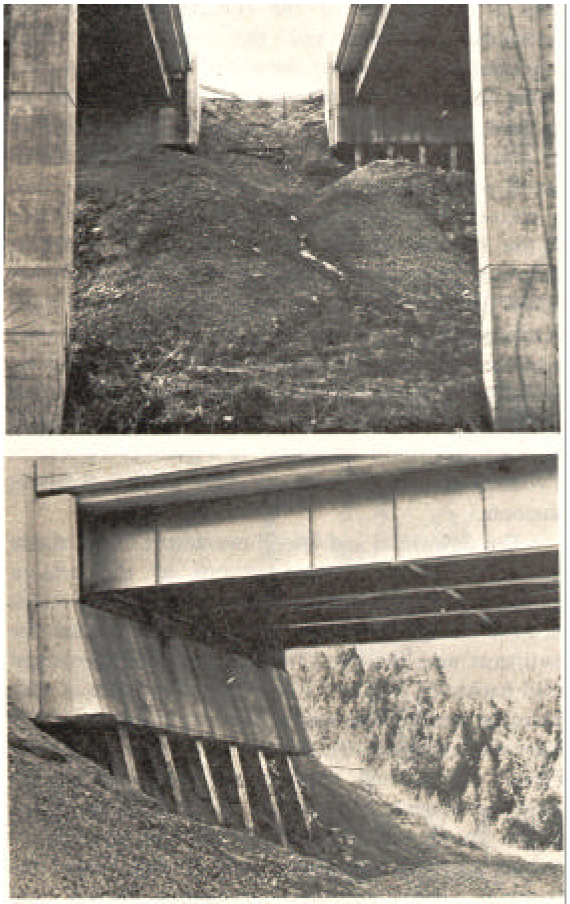


Figure 6. Views of western embankment slope failure and exposed abutment piling on the Bluegrass Parkway across Chaplin River (after Hopkins 1973).

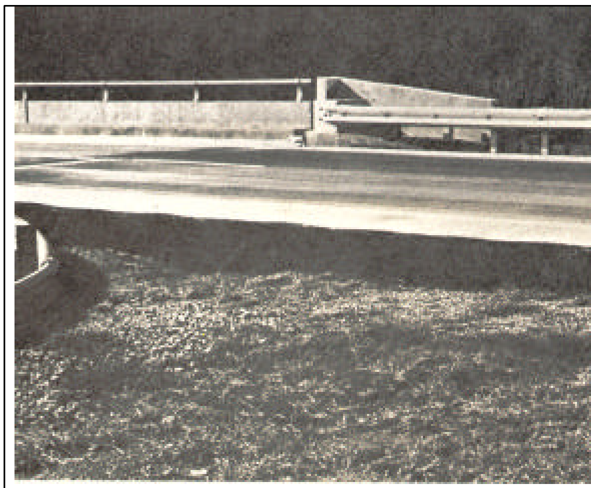


Figure 7. View of the heavily patched eastern bridge approach caused by large settlements and movements of the abutments toward the river (After Hopkins and Yoder 1973).

Some of the more expensive embankment failures have occurred in bridge approach embankments (Hopkins 1973; Hopkins and Yoder 1973). For instance, in 1969 the eastern and western embankments of the twin bridges on the Bluegrass Parkway spanning Chaplin River, shown in Figures 6 and 7, were failing and moving toward the concrete abutments. The movements were so severe that the concrete abutments had developed large cracks and the real danger existed that the large bridge approach embankments would completely collapse and drop all end spans of the twin bridges into the river. Such action would have closed the parkway for several months. Causes of the failures were ingress of the water table into the embankments, weak clayey shale foundations, rapid drawdown, toe erosion, and very steep slopes (1.5 horizontal to 1 vertical). The ends of the bridges were lengthened and the embankment slopes were decreased to about 3 horizontal to one vertical. Cost of repairs was 1.5 million dollars. Today, this repair job would be several million dollars because of inflation.

Another bridge approach embankment failure, which occurred in 1983, is shown in Figure 8. This two-lane bridge carries U. S. 68 across the Licking River in Nicholas County. The 120-foot bridge approach embankment was moving rapidly toward the bridge abutment and threatened to close the highway. Highway closure would have cause a several-mile detour. Consequently, government officials did not allow decreasing the slope of the embankment and lengthening the bridge. Moreover, this bridge-lengthening solution was estimated to exceed 3 million dollars. Causes of this failure were ingress of the water table into the embankment, weak clayey shale and soils, rapid drawdown, and toe erosion. A rock shear key and berm was designed (Figure 8)

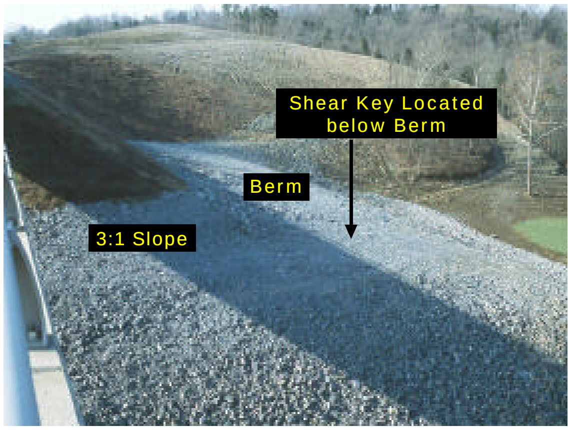


Figure 8. View of the construction of a shear key and berm to halt movement of the failing southern bridge approach embankment on U.S. 68 across Licking River in Nicholas County, Kentucky.

and used to repair the moving embankment at a cost of 750,000 dollars (Hopkins 1983). Slope inclinometer readings showed that the embankment essentially ceased movement about 2 years after construction of the shear key and berm.

Highway rock slopes, which have been exposed to rain and snow, many cycles of freezing and thawing, extreme differences in temperature, and natural chemical reactions, weather over time and frequently produce rock falls that are hazards to the traveling public (Hopkins, Beckham, and Puckett 1996, Hopkins and Gilpin 1981, and Hopkins and Deen 1983).

Through research, many of the past inadequacies have been addressed and improved design and construction standards that emerged are used today in constructing new, or reconstructing older, highways. This has aided in mitigating the occurrence of landslides and rock falls on new highways. However, only when new construction, or reconstruction, occurs can new design and construction techniques address the problems of aging embankments and rock slopes. Older highways, which suffer from deterioration or inadequate design and construction standards, will continue to present maintenance problems.

The maintenance of highway slopes and the correction of landslides were identified by engineers of the Kentucky Transportation Cabinet as major engineering problems that involve considerable expenditures (millions of dollars) of funds each year. The Federal Highway Administration (FHWA) has strongly suggested to all states that a landslide and rock fall inventory be developed so cost estimates and, eventually, remedial plans may be developed. Such information could be used to inform the United States Congress for potential funding and to create a program similar to the Bridge Replacement Program. The actual numbers of landslides and hazardous rock slopes existing on highways under the jurisdiction of the Kentucky Transportation Cabinet are unknown. But engineers believe the numbers are sizeable. This report and the inventories of landslides and rock slopes performed on Kentucky's highways and described herein are in response to the suggestion by FHWA, Hopkins, et al (1988), Mathis[1], and Lutton (1977). The report also represents an attempt to define the scope of landslide problems in Kentucky on major routes. This report and a landslide database provide actual numbers of landslides under the jurisdiction of the Kentucky Transportation Cabinet. The numbers of rock slope problems existing on Kentucky highways has been published previously in companion reports (Hopkins and Beckham 1996: Hopkins, et al, 2003). A database of rock slope identified as hazardous was also constructed and is on a server of the Kentucky Transportation Cabinet. These efforts represent the first major step in attempting to correct landslides and rock fall problems in Kentucky. To develop an effective management plan requires identifying and developing information of landslide and rock fall sites where future

[1] Private communication, former geotechnical engineer and Branch Manager of the Geotechnical Branch, Division of Materials, Kentucky Transportation Cabinet, Frankfort, Kentucky.

corrections and reconstruction may be needed to improve safety and to maintain, or increase the traffic capacities of roadways.

In planning, reconstructing, or maintaining, highways, knowledge of the occurrences and types of rock falls and landslides and engineering properties of soils and rocks in an area is essential to optimize design and minimize costs. From past experience, the cost of excavating and placing soil and rock is some ninety percent of the total cost of constructing a new highway in mountainous country. In flat to rolling terrain, the cost is some fifty percent of the total cost. The performance of a highway is directly related to types of soil and rock located in the highway corridor. Slope geometry selected for embankments and cuts in mountainous country largely affect both initial and future maintenance costs of the highway. Stabilities of embankment slopes and rock cuts are dependent on strength properties and weathering characteristics of the geological (rock and soil) units. Strengths of compacted soils and rocks greatly control the slope angles of embankments. Both cut and embankment slope angles dictate right-of-way requirements. The engineering properties of the materials used in the embankment subgrade have a large affect on the performance of the pavement. Excessive settlement, failure of the embankment, or a weak subgrade can cause premature failure of the pavement. Uneven pavements can cause traffic safety problems. Consequently, in planning highway facilities, first-hand knowledge of geotechnical information of the soil and rock units of an area during the design phase is invaluable. Moreover, knowledge of past performances of soil and geological units in rock cut slopes and embankments can aid in reducing failures. The number of past embankment and cut-slope failures in a region alerts the designer of potential design problems.

OBJECTIVES AND SCOPE

The major objective of this study was the establishment of a comprehensive system for managing landslide problems in Kentucky. To accomplish this objective, two major steps had to be completed. As a means of managing efficiently a massive amount of information, a geotechnical database was developed and is described herein. The database resides on a server of the Kentucky Transportation Cabinet. The computer program was developed in a Windows format and as a client-server application. Numerous computer graphical user interface (GUI) screens were programmed for entering and retrieving landslide and rock slope information. The Geotechnical database contains four major components: landslide, rock slope, structures, and soil and rock information. Secondary components include engineering and statistical applications. Although the database contains several components, this report mainly focuses on the landslide portion of the database.

The second important step of this study consisted of surveying thousands of landslides and rock slopes located on Kentucky's highways. Photographs and the latitudes and longitudes of all landslides and hazardous rock slopes were located using Global Positioning System (GPS) equipment—sub-meter accuracy. All twelve Highway District Offices and several Central Offices (in Frankfort) of the Kentucky Transportation Cabinet are connected to the database and server. Hence, authorized district and central office personnel can interact with the database. Personnel can easily recall and view the photographs in the database and the attributes of all landslides and rock slopes. Other components of the database are under development and will be described at a later date. The landslide and rock fall modules of the geotechnical database establishes a priority program for allocating and funding the repairs of landslide and rockfall sites under the jurisdiction of the Kentucky Transportation Cabinet. Information in the database is used in the development of the Cabinet's six-year plan.

The Kentucky Transportation Cabinet is also sponsoring additional research on the development of the geotechnical database. Other components of the geotechnical database are under development. One major component involves storing the soil and rock data that are routinely generated by the Geotechnical Branch in their normal operations. Graphical user interfaces are under development for entering historical soil and rock data. As much data as practical are being entered during the study period. Graphical user interfaces are being developed for "capturing" soil and rock data in a real-time mode, or as the data is generated. This work will be reported at a later data. Rock slope and database work began in 1993. This report, a report published in 1996 (Hopkins et al,) and two additional, pending companion reports are a culmination of this work.

DEVELOPMENT TOOLS

Where wide interest in stored information may exist, numerous users may want to access the data at the same time. Hence, the database software must contain a feature to permit this type of accessibility. In anticipating this need, the Kentucky geotechnical database was constructed using Oracle® 8i database software (Aronoff, et al. 1997; Devraj 2000; and Gruber 2000). PowerBuilder® software (Sybase 1999a, b, c), a product of SYBASE®, was used to build graphical user interfaces (GUI). This software is an object-oriented, development tool that allows the user to build powerful, multi-tier applications that can run on multiple platforms and interact with various databases, as illustrated in Figure 9. It provides the necessary tools to develop client/server applications and provides strong support for development in Data Windows and graphical user interface environment. The Data Window, Figure 10, is a powerful tool for building graphical user interfaces. The database can accommodate any number of "user hits" at essentially the same time. One example of the usefulness of this feature is illustrated in Figure 11. In this example, personnel located at district offices and geotechnical personnel in the central office can view the same data and photographs stored in the database of the same site at the same time and discuss (by telephone) the attributes of the site. Hence, this feature provides a quick means of assessing a situation before traveling to the site.

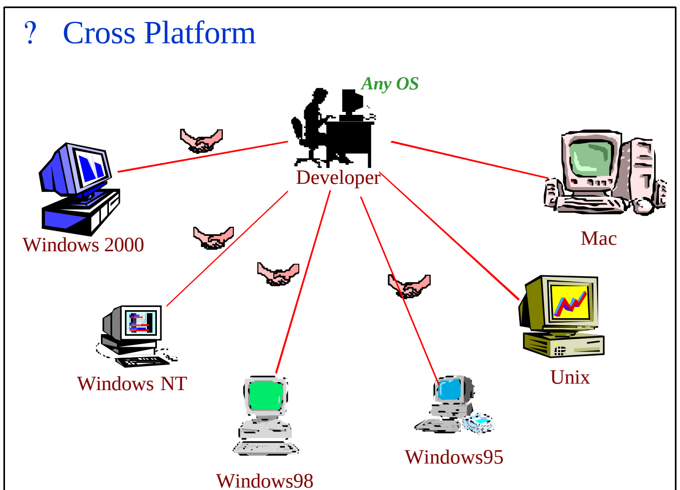


Figure 9. Cross platform capabilities of PowerBuilder® Software

By using MapObjects® software (ESRI 1999a, b)--a Geographical Information System (GIS) product of the Environmental Systems Research Institute, Inc. (ESRI®)--and locations from GPS equipment, data site distribution can be viewed on different types of Kentucky maps. MapObjects® consists of a set of mapping software components that allows maps to be included

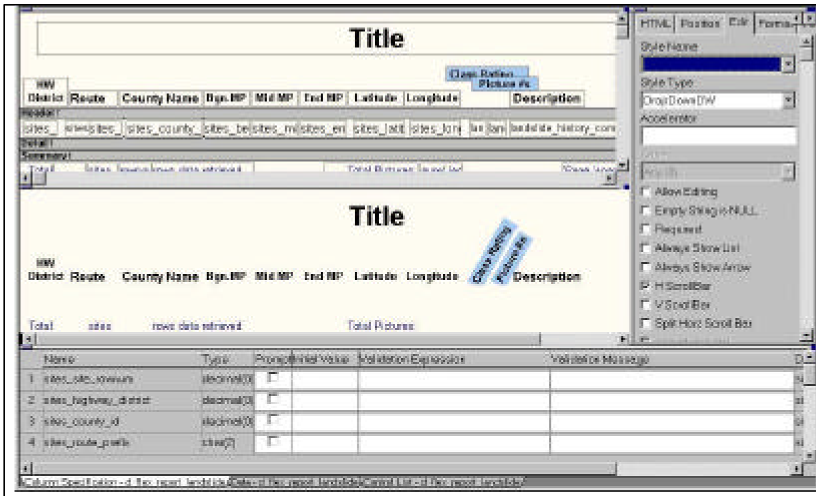


Figure 10. Data Window of PowerBuilder® 8.0.

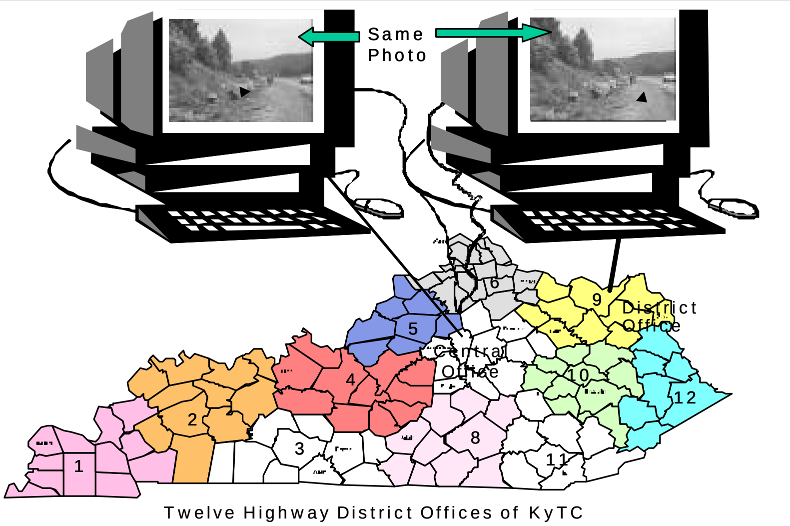


Figure 11. View of the same site photo by personnel at the same time at different locations.

with user applications. It comprises an ActiveX control (OCX) called the Map control and a set of over forty-five ActiveX Automation objects. Programs built with MapObjects® will display a map with multiple GIS map layers, such as roads, landslides, rock fall sites, geotechnical borings, streams, and boundaries. Features can be selected with an SQL expression and real-time or time-series data can be displayed dynamically. Embedding MapObjects® in PowerBuilder® applications provides both powerful map and data processing functions, which were instrumental in developing a successful application. Digitized 7.5-minute geologic quadrangles, produced by the Kentucky Geological Survey, can be stored on a local computer, and displayed with the databases. Other embedded maps include county roadway maps. Electronic photographs are stored as a JPEG (Joint Photographic Experts Group) file.

LOCATION OF SITES

Conventional Schemes of Locating Sites

The essential meaning of the prefix geo refers to specific properties of the planet earth and location is one of those properties. In the early development of the geotechnical database, it was recognized that the ability to physically locate the various geotechnical sites and data entries of associated attributes in the database was of paramount importance. Without the means of identifying the exact location on the earth of a boring or other highway feature limits the usefulness of geotechnical data in the database. Moreover, it was also realized that the ability to view these locations in relation to each other was also valuable. Each variable and its assigned properties had to be assigned a position on the earth whether numerical or textual to allow comparison to like variables and to allow navigation to the variables. Physically locating a site in the field using conventional schemes, such as surveying, is very difficult and time consuming.

For example, when a highway project is initially constructed, station numbers are used to identify the different locations of the boreholes, embankments, slopes, culverts, bridges, and other essential features of the project. During construction, Stakes driven into the ground at fixed intervals, or station numbers, of length, identifies locations of the various features of the project. Hence, if a particular soil boring shown on a plan at a certain station number needs to be identified in the field, then that particular hole could be located physically by finding the stake with the proper station number. Unfortunately, station numbers (stakes) are destroyed during and after construction and do not provide a means of identifying a particular location after construction. The stakes are only used during construction and are temporary because they are made of wood and rot after some time. Moreover, the station numbers of numerous past highway projects are frequently not tied to a fixed and accurate point on the earth. To locate a highway feature after construction using standard surveying techniques would be too costly and generally impractical.

Consequently, a system evolved for identifying locations of highway features in the field by assigning a particular location to a county name, the highway (route) number, and the mile point. Using this conventional system, which is only approximate, allows engineers to physically locate in a fairly reasonable manner a highway feature in the field. It also allows a rough estimate of comparison of locations from a map. Because this system continues to be used today by operation engineers and others, this method of identifying and referring to a location of a highway feature was retained in building the geotechnical database.

Although identifying a location by county number, route number, and milepost has provided a fair means of identifying a highway feature in the field, this system is oftentimes inaccurate for a number of reasons. First, odometers on different vehicles are not accurate to the tenth of a mile. Different vehicles may yield different locations, although they may began at the same location, they may yield different locations. Secondly, reconstruction of new highways in Kentucky very often results in a change in mile points. Generally, reconstruction tends to shorten an old road and change existing mile points. Sometimes the highway route number itself changes, as illustrated in Figure 12, and the locations become virtually useless. The conventional system that is widely used for defining a location by county number, route number, and mile point is not unique because the identifiers of that location are subject to change in the future. Because of the nature of these possible errors, a system was needed to provide a unique

Figure 12. After reconstruction, US 23 in Johnson and Floyd Counties was renumbered KY 321 in the mid-nineties.

means of identifying highway sites, or features. Some geotechnical data such as borings could not be referenced to the mile point system and were lost.

Application of the Global Positioning System (GPS) for Locating Sites

To overcome difficulties associated with the mile point system and conventional surveying, and beginning in 1998, Global Positioning System (GPS) equipment was acquired and used to locate hazardous rock fall sites and landslides along Kentucky's highways. The GPS system provides an excellent way of identifying a highway feature by latitude and longitude, which are unique numbers. This equipment produces accurate coordinates that do not change as the arterial highway system changes in Kentucky.

The unit first used to locate sites in Kentucky was Trimble's ProXR mapping grades system. This unit provides a location accuracy of one-meter (or sub-meter) horizontal and six meters vertical. The unit is portable and can be carried as a pack Figure 13, or mobile mounted in a vehicle, as shown in Figures 14 and 15, respectively. Set-up time is about five minutes with no permanent changes to the vehicle. The self-contained system consists of an antenna (Figure 14), receiver, and data logger (Figures 15). The Trimble ProXR antenna also allows real-time correction in the field with the use of a built-in radio antenna that receives signals from near-by beacons transmitting fixed correct coordinates. The unit also features multi-path rejection technology. As a pack unit, the ProXR is very concise. However, the large weight of the unit discouraged the use of the pack as a common practice. As a mobile mount, it can be separated for ease of use. The antenna uses a magnetic mount that holds fast to the top of any vehicle. While this system eliminated the problems with the mile point system, some minor problems arose, such as the weight problem, using the system.

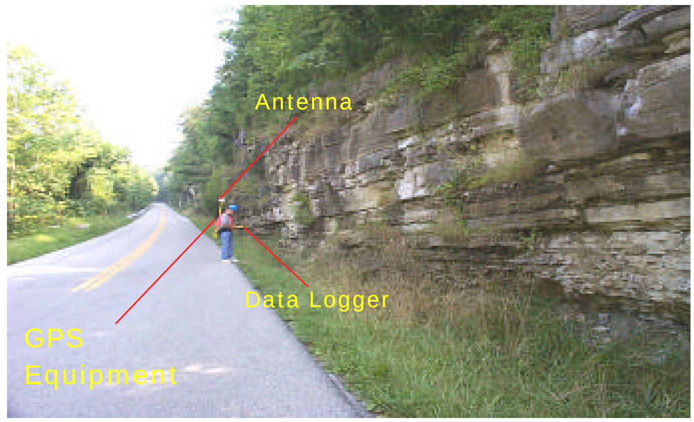


Figure 13. Portable GPS pack by Trimble?

Figure 14. The Trimble? ProXR, vehicle-mounted antenna.

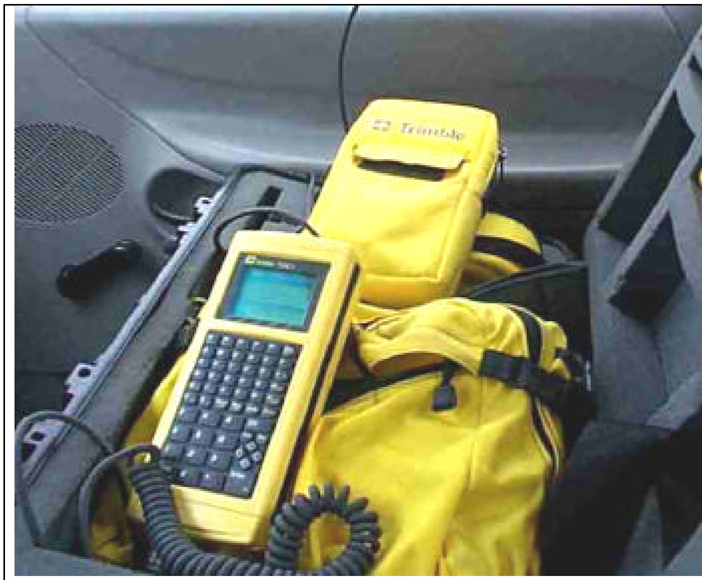


Figure 15. Data logger

The Global Positioning System operates by producing a pseudo random code and comparing it with the same code embedded in a radio signal transmitted by satellites orbiting the earth. In theory, these codes are produced at the same time. The time difference from the instant the receiver produced the code and the instant the code was received from the satellite is used to calculate distance. Signal from at least four satellites is needed to produce three-dimensional positions. There are 24 satellites that make up a constellation in a non-geosynchronous orbit 12,600 miles above the earth. These satellites, called space vehicles by the GPS, are in constant contact with each other and continually upgrade the receiver's clock using onboard atomic clocks accurate to one ten millionth of a second.

A signal from the first satellite locates the position to a point on a sphere. A signal from the second satellite places the position at the intersection of two spheres. The signal from the third satellite narrows the position to one of two points made by a third intersecting sphere. The forth satellite locates the true point three dimensionally as the fourth sphere intersects the first three at the point. This process is known as satellite trilateration and is one of five principles of operation along with satellite ranging, accurate timing, satellite positioning, and correcting errors.

The calculations behind satellite ranging assume the signals travel at a constant speed, the speed of light. Because this is only a constant in a vacuum, errors are inherent and must be corrected. Upon striking the earth's atmosphere, the signal from the satellite must pass through the D layer of the atmosphere. Solar rays charge the atmosphere and the radio signal is absorbed. It also passes the troposphere, which creates lag as well. The department of defense does correct clock and orbital errors having to do with timing and positioning. Multipath interference occurs when the signal is reflected off other objects such as buildings before reaching the receiver. The antenna on the ProXR detects and rejects such signals using advanced signal processing.

Essentially, three methods are available for obtaining data using the ProXR. The first method consists of simply recording the position read in the field onto a data sheet. The second method requires logging a number of positions into a file (rover file), downloading these into a desktop computer program, and comparing them with positions (base files) taken by another receiver over a known point. If they are close enough together, they should "see" the same constellation of satellites and record the same error allowing the correction to be applied to your new field point. This is called "Differential Correction." The third method actually does this correction in the field by receiving a low-power AM signal from a nearby beacon. This is termed "Real Time Differential Correction."

Most rockfall and landslide sites have been located using the mapping-grade GPS equipment. This technology has also been used to map and define some highways, including bridges and culverts. This system provides a way to link the two methods of locating these structures together. Using a “data dictionary” in the data logger’s software, all the location data including, county, route and mile point can be entered and saved with the position record. The data logger is also able to record the date and time and name of the person using the equipment. Also it keeps an embedded record of what satellites it used to calculate the positions and the condition of the signal. These two items are termed an ephemeris and almanac. Upon returning to the office, all data are “dumped” (via serial port connection) into the desktop processing software where it is corrected, if needed, and all points are processed and averaged to give the most accurate location. The data can also be viewed or exported to a number of formats. The ProXR allows “real-time correction,” as well as differential correction. The receiver monitors for any beacon signal. The handheld data-logging unit stores all data taken by the receiver in a “Rover-File”. The unit is self-contained in an airtight hard-shell case, as shown in Figure 14. The Pathfinder software program is included with the unit and is used to process, view, and export positions taken by the ProXR. It also allows the manipulation of datum, projection, and units of display and is capable of plotting directly to a printer, as shown Figure 16.

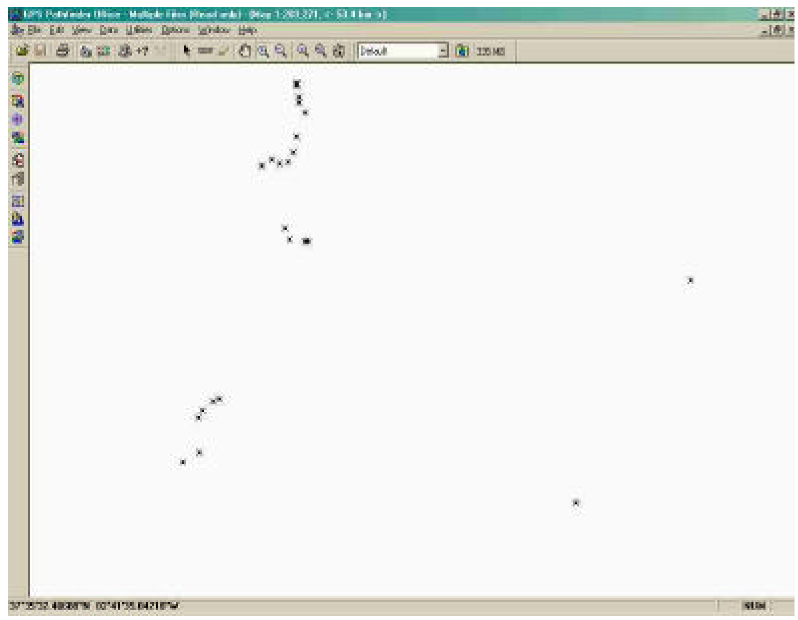


Figure 16. Plot of mapped positions.

After all data are corrected and ready for use, it is exported to an ASCII format and printed. At this point, all data concerning the site are available, as well as the site position. This printout is used by the person(s) inputting the site information into the geotechnical databank. After all positions are entered and stored on the databank, this printout is placed in a binder with the original field data sheets for future reference. The digital file is placed in a file according to highway district and backed up to a CD regularly along with the corrected data logged files.

Exporting it to a GIS format and opening the data using a GIS program, such as ArcGIS, can make further use of the data. Using the measured field positions, the locations of rock fall, or landslide, sites can be placed on aerial photographs to obtain a better view of where the sites are in relation to their physical environment. From this information, picture files can be created and placed with a specific site in the data bank. Viewing the sites on an aerial photograph may provide users an insight as to the cause of a problem or give a view of terrain that must be negotiated to get to a particular site.

Figure 17. Locations of landslides superimposed on an aerial photograph along KY 9 in Boone and Kenton Counties, Kentucky.

To illustrate, the latitude and longitude of several landslide areas along KY route 9 have been plotted on an aerial photograph, figure 17, or an ortho-photo quarter quandrangle, of a particular stretch of the Ohio River. Apparently, the landslides are occurring in the bends of the river at this location that are most susceptible to erosion along the base of the embankments and natural slopes. Natural slopes in this area are composed of residual soils that were derived from the Kope Geological Formation. These soils and the Kope shales were used to construct the embankments of KY 9. The clay shales of the Kope Formation have been involved in numerous landslides of this area. As support of the slopes is lost, the embankments and natural slopes gradual "creep" down slope. Eventually, as the erosion and creep continue, and with the occurrence of rapid drawdown during flooding, the slopes fail. Viewing landslides in this manner can aid in determining the major causes of landslides in certain regions.

Conversion Between State Plane Coordinate System (SPCS) and Geodetic Position Latitude/Longitude

Algorithms for converting state plane coordinates and geodetic position, latitude and longitude, have been presented elsewhere (Hopkins, Beckham, Sun, and Butcher, 2003)[2] in detail. If the latitude and longitude of a site are known, then they are automatically converted and stored in the database. This includes The State Plane Coordinate System of 1927 (SPCS 27) and 1983.

Coordinates of Sites Stored and Displayed in the Geotechnical Database

To facilitate data entry into the geotechnical database, data pertaining to any selected coordinate system may be entered. Those systems include SPCS 27, SPCS 83, degree-minute-second Latitude/Longitude, or decimal Latitude/Longitude. Once data is entered into a selected coordinate system, algorithms, described previously, in the geotechnical database automatically convert the entered data into the coordinates of the other coordinate systems and automatically display on the screen all coordinates for all coordinate systems. For example, other coordinate systems will automatically convert to other system's coordinates by corresponding formulas, as described in the previous sections, only decimal Latitude/Longitude data will be saved to the database. When the existing decimal Latitude/Longitude data are retrieved, the coordinates of the other three systems are calculated and displayed on the screen, as shown in Figure 18.

[2] The algorithms were programmed into the Kentucky Geotechnical database by Liecheng Sun.

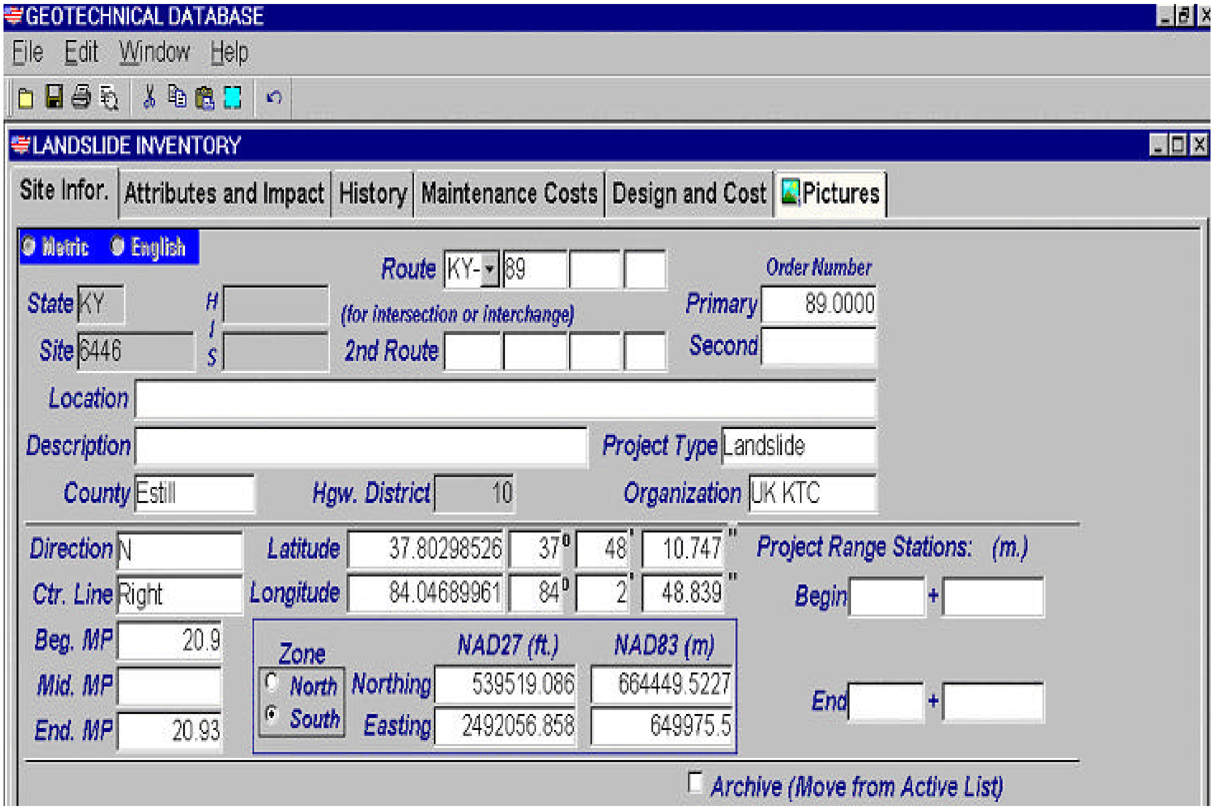


Figure 18. Display of coordinates in different coordinate systems.

GENERAL DATABASE STRUCTURE

The main objective of a database application is to devise a system for entering, retrieving, and analyzing data, effectively and efficiently. To achieve these aims, many different datum categories were created within the geotechnical database. To use them effectively, the different datum categories not only have to be isolated individually, but they also have to be linked together in the database. For this purpose, and to create a hierarchy that is logical, flexible, and easy to understand, the database was divided into several different levels to accomplish a "tree-like" design and linked using primary and foreign keys (Aronoff et al 1997). A primary key is a column or a set of columns that uniquely identifies each row in a table. A foreign key is a column or a set of columns that contains primary key values from another table. Each item in the column or columns must correspond to an item in the column of the other table. There are natural and relational connections among those geotechnical data by location. Based on location, the data are divided into different levels. The location/site is the highest-level datum. Any geotechnical datum has that information. Below that level are different project categories, more detail and lower level data such as holes, sample, and properties. Under this relational structure, storage requirements of the database are minimized.

The "tree-like" structure and datum relationships of the different components of the Kentucky Geotechnical Database are illustrated in Figure 19. The data are partitioned into five major categories:

1. Rock Slope Database
2. Landslide Database
3. Roadway Database
4. Structures Database
5. Soil and Rock Engineering Database

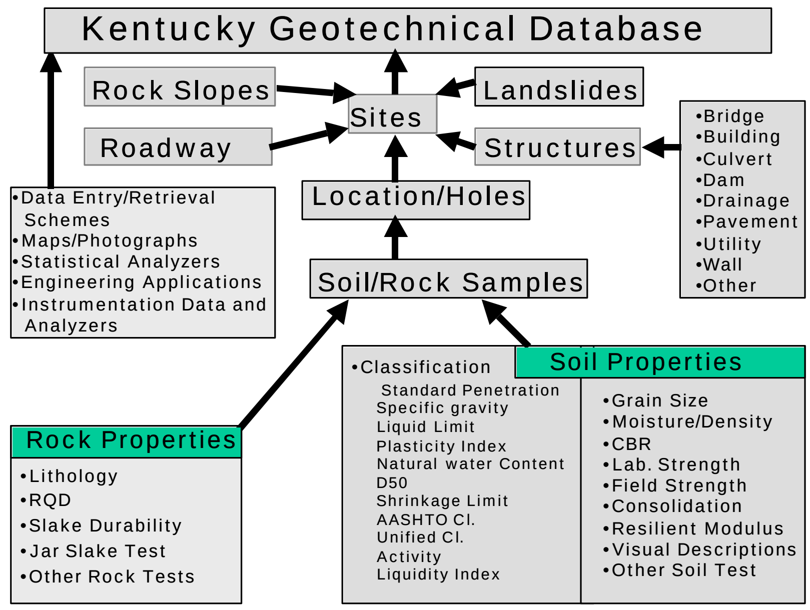


Figure 19. Structure of the Kentucky Geotechnical Database

Structures include bridges, buildings, culverts, dams, drainage, pavement, utilities, walls, and other types of structures identified in the future. Test properties of soils include classification, grain size, moisture-density relations, CBR, field and laboratory strengths, consolidation, resilient modulus, shear strengths, and visual description. Test results entered in the classification category include specific gravity, liquid limit, plasticity index, natural water content, D_{50}, shrinkage limit, AASHTO soil classification, unified soil classification, soil activity, and soil liquidity index. Test properties of rocks include lithology, rock quality designation (RQD), slake-durability, and jar slake test. Other components of the database include data entry and retrieval schemes, analytical and design applications, statistical analyzers, and electronic photographs and maps.

MAIN MENU

The main menu of the geotechnical database is shown in Figure 20. When the "Add a New Project" on the main menu is clicked, the graphical user interface illustrated in the right-hand portion of the figure appears. The sub menu offers the user three choices. When "Site" is selected, the GUI screen shown in Figure 21 appears. The "Site" GUI screen contains entry boxes for several different types of information. Types of information that may be entered include route number, general location, description, county, project type, direction (of route), position of site relative to centerline, beginning and ending mileposts, latitude and longitude, and

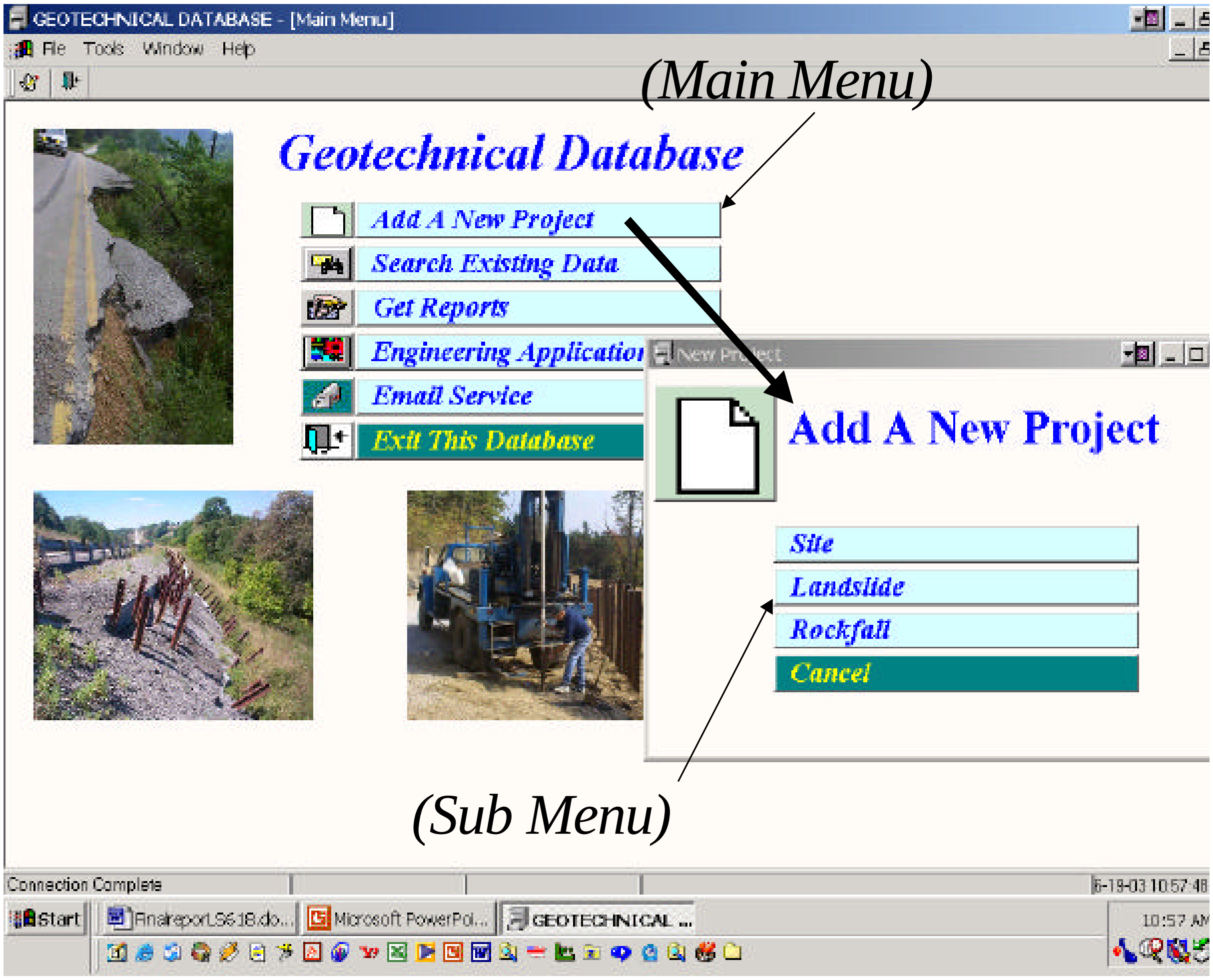


Figure 20. Main menu and "add a new site" menu of the geotechnical database.

beginning ending station numbers. Project types include building, bridge, culvert, dam, landslide, planning study, pavement, rockfall, roadway, SCS (Soil Conservation Service), utilities, and wall. The site number is automatically generated by the database. Geotechnical engineers of the Geotechnical Branch (Division of Materials) of the Kentucky Transportation Cabinet assign the ordering number. Programmed algorithms in the database automatically convert latitude and longitude to state plane coordinates and vice versa. The GUI site screen shown in Figure 21 is used for entering data for landslide and rock slope sites. If other types of sites are selected in the dropdown list (shown in Figure 21), then the GUI screen in Figure 22 appears. This screen is common for sites labeled as building, bridge, culvert, dam, drainage, pavement, planning study, SCS (Soil Conservation Service), and wall. Walls are further subdivide into different types. These include MSE (mechanical stabilized earth), gravity, semi-gravity, cantilever, noise, crib, and CMU walls.

GUI screens for entering detailed information for any given type of site may be accessed from the site screen by clicking the attributes' button shown in Figure in 23. For example, if the site type selected (dropdown list in Figure 21) is "Roadway" and the user clicks the attributes' button, as shown in Figure 23, the user initially retrieves a message shown in that figure. If "yes" is clicked, that is, the user chooses to save the site information, then the user is connected

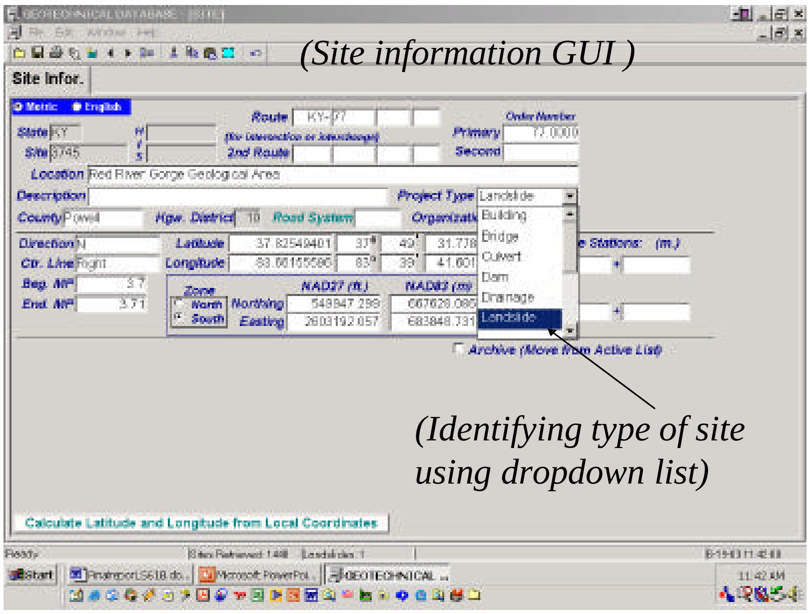


Figure 21. GUI screen for entering site information.

to the roadway GUI screen shown in Figure 24. The "Roadway" GUI screen contains tabs identified as "Site Infor," "Work Phase," and "Roadway." Data entered on the site Roadway GUI is illustrated in Figure 22. In addition to the data shown in Figure 22, the GUI also contains other information, such as number of phases, number holes at the site, an indication that the data contains tested soil, soil visual descriptions, railroad crossing, stream name.

Clicking the tab identified as "Work Phase" causes the GUI screen shown in Figure 24 to appear. Any number of work phases may be entered by "right-clicking' the mouse on an entry box. A dropdown menu is obtained, as shown in Figure 24, when the user clicks "add" and a new line appears for adding new work phase details. Phase number, date of drilling, accuracy of hole location (x, y, and z), datum, surface elevation correction, item number, and engineering units for original work are types of information that may be added. Data entry fields are available for entering the work phase number, and the agency performing the laboratory testing, the agency performing the geotechnical analysis, the designer. Also, there are data fields for showing the report number, who wrote the report, who issued the report, and completion status.

When the "Roadway" tab is clicked, the GUI screen tab shown in Figure 25 appears. This screen contains data fields for entering such information as the beginning and ending station numbers and such information as associated structures and features, equations for roadway, side roads, history pertaining to design, construction, and performance problems. Other GUI screens containing tabs for entering detailed information for buildings, bridges, culverts, pavements, drainage structures, planning surveys, and walls are available, or under construction.

As shown in the site sub menu Figure 20, direct links to "Landslide" and "Rock Slope" sites were made. During collection phases, enormous amount of information pertaining to landslide and rock slope problems were being entered on a daily basis. The direct links provided a convenient means of entering that data.

A general overview and brief descriptions of the major components of the geotechnical database are given below. A detailed discussion of the landslide database management system is presented below. Detailed descriptions of the rock slope database management system have been presented elsewhere (Hopkins, et al, 2003a). A complete detailed description of the Kentucky Geotechnical Database will be documented in a future research report.

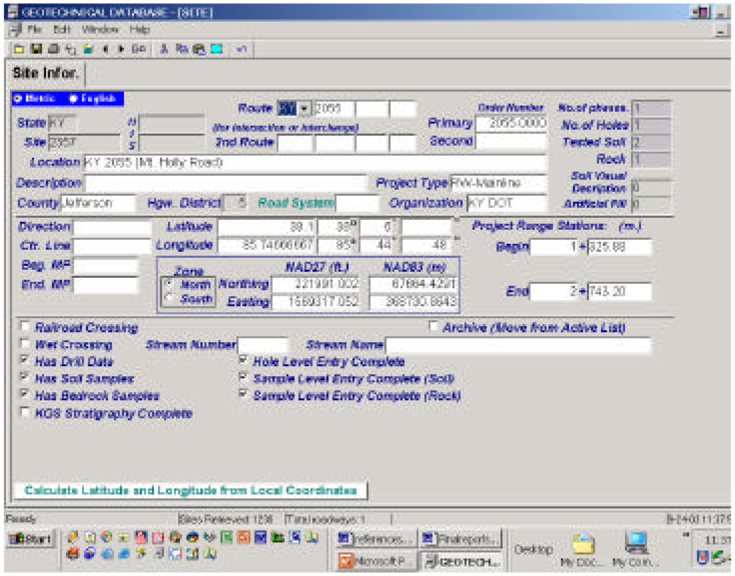


Figure 22. GUI screen for entering different types of sites

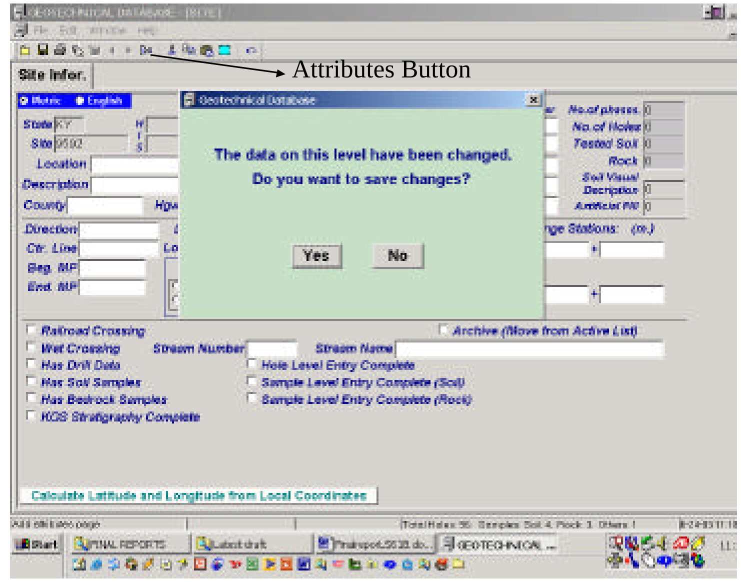


Figure 23. Attributes' link to other GUI details.

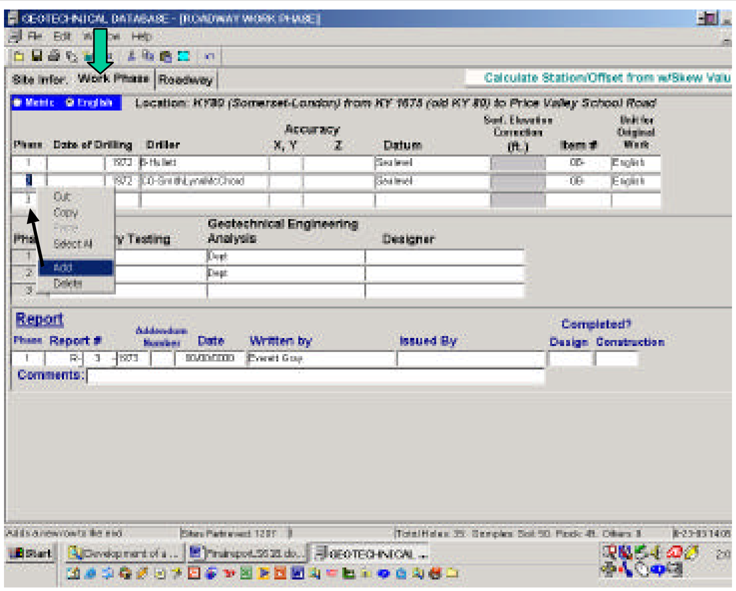


Figure 24. GUI screen for entering Roadway phase data.

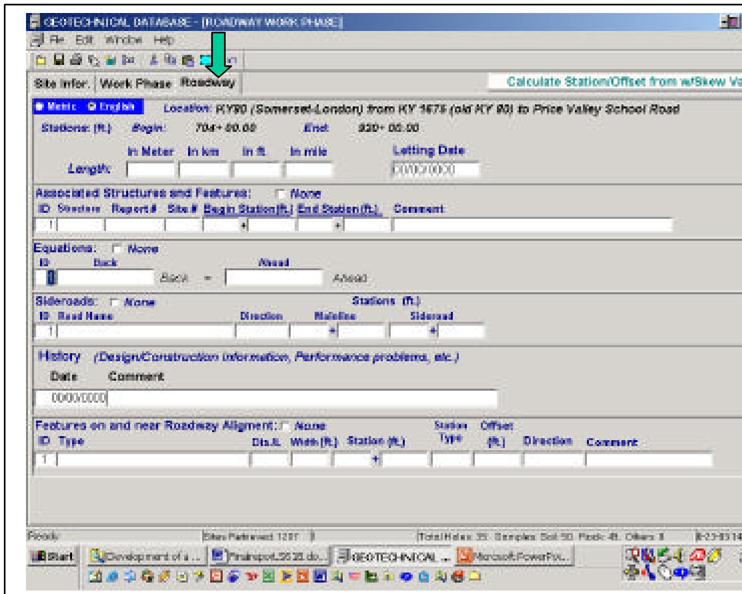


Figure 25. GUI screen for entering Roadway details.

Description of Landslide Database and Management Program

The landslide data module of the database contains an inventory of landslides that are occurring, or that have occurred, on Kentucky highway routes. The database contains approximately 1300 landslides inventoried by the University of Kentucky Transportation Center and data for about 1,400 landslides imported from a database maintained by the Kentucky Transportation Cabinet. Landslide sites can be sorted according to district, county, route number, and mile point.

Figure 26. Past maintenance activities at a landslide site on US 68 in Mason County.

Landslide slide inventory data was collected using a data format that is used by the Kentucky Transportation Cabinet with some minor modifications. This form was devised from guidelines originally proposed by Hopkins, et al (1988). Information collected for each landslide includes project, site, maintenance history, and severity rating. Project data includes county, route, milepost, and latitude and longitude. Site information includes the type of slide (embankment or cut slope), height of embankment or cut, length of slide, and a general description of the site. Maintenance data includes average annual daily traffic, maintenance expenditures, and past types maintenance activities, as illustrated in Figure 26.

Landslides are categorized by the following severity descriptions:

- A Very Serious—failure has occurred, or is imminent, road is closed, one lane condition exists, buildings in danger, or a major safety concern exists.
- B Serious—landslide is moving rapidly requiring constant maintenance (daily, weekly, monthly, etc.).
- C Moderate—some movements, breaks in pavement (occurrence over several years).
- D Minor-- slope failures affecting slope only, slight, or no, movements at the present time.

Site location and landslide attributes are entered using GUI screens similar to those used for rock fall sites. Additional screens are available for entering maintenance activities and costs, utilities present, adjacent properties and other factors. This format allows easy review of maintenance costs and activities at landslide sites. The main landslide GUI data entry screen is depicted in Figure 27. Details of this portion of the database are described in a companion report that is pending.

When "Landslide" is clicked in the "Add a New Project" submenu (Figure 20), the landslide GUI screen shown in Figure 27 appears. This Graphical user interface screen contains tabs for retrieving other landslide data entry GUI screens. The tabs are identified as Site Information, Attributes and Impact, History, Maintenance Costs, Design and Cost, and Pictures. By clicking the Site Tab, the GUI screen in Figure 21 appears. The site screen for landslides was described previously.

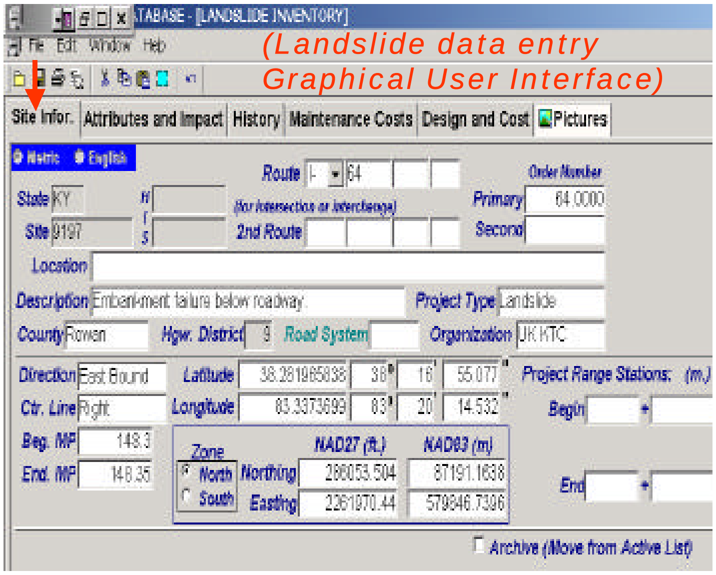


Figure 27. Graphical user interface for entering landslide site information and tabs for retrieving other landslide data entry graphical user interfaces (GUI).

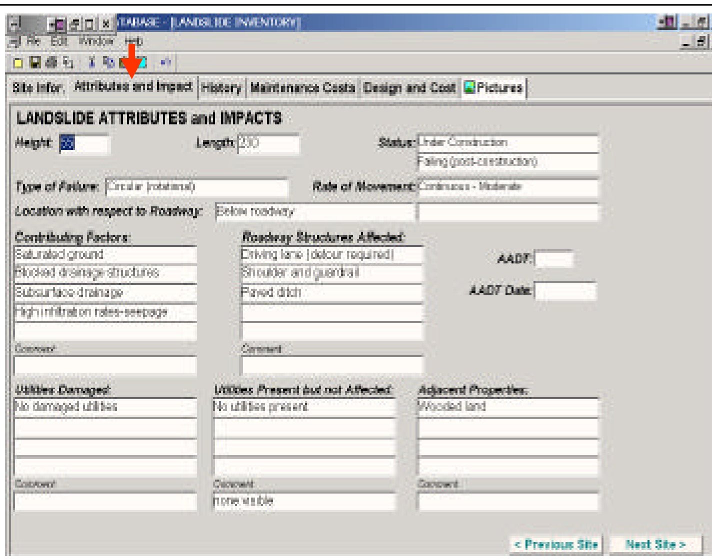


Figure 28. GUI screen for entering attributes and impact information pertaining to the landslide.

When the tab identified as “Attributes and Impact” is clicked, the GUI screen in Figure 28 appears. Values of height and length of the landslide can be entered on this GUI screen. The status of the landslide may be noted using a dropdown list. Choices include failing, monitoring failing slope, design in development, under construction, and corrected. The user may use a dropdown list of “Contributing Factors” to estimate those factors that may be contributing to the landslide movements or failure. Some choices include surface drainage, broken drainage structure, blocked drainage structure, ponded water, and other factors such as toe erosion and flooding (rapid draw down). The GUI screen has a dropdown list for noting the type of structures that may be affected by the landslide. Information regarding damaged utilities and utilities that are present but not affected by the landslide may be entered. Using a drop down listing, the user may specify the type of adjacent properties that may be present. Some choices include agriculture land, commercial, industrial, park, railroad, residential, and wooded area. The AADT (average annual daily traffic) may be posted.

By clicking the “History” tab, the GUI screen shown in Figure 29 appears. A continuous record of the history of the landslide may be maintained. Additional lines may be added by “right clicking” the mouse. Information includes the person examining the slide, date, and comments. A GUI screen for maintaining maintenance costs and the actions performed are shown in Figure 30. A dropdown list of activities is provided so that the user does not have to manually type the action performed. Views of the landslide may be obtained by clicking the tab “Pictures.” The “Pictures” GUI screen for viewing and entering photographs is shown in Figure 31. By double clicking on a selected photograph, the user may enlarge the small photograph for better viewing (Figure 32).

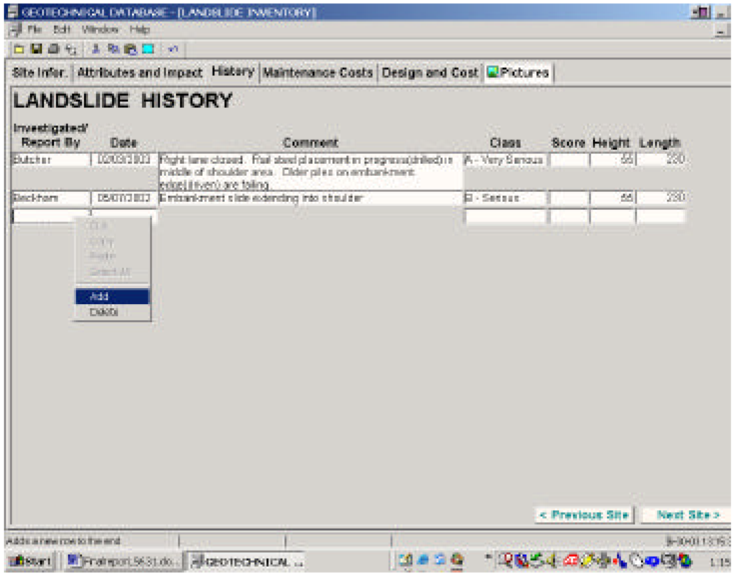


Figure 29. Data entry GUI screen for maintaining a history of the landslide.

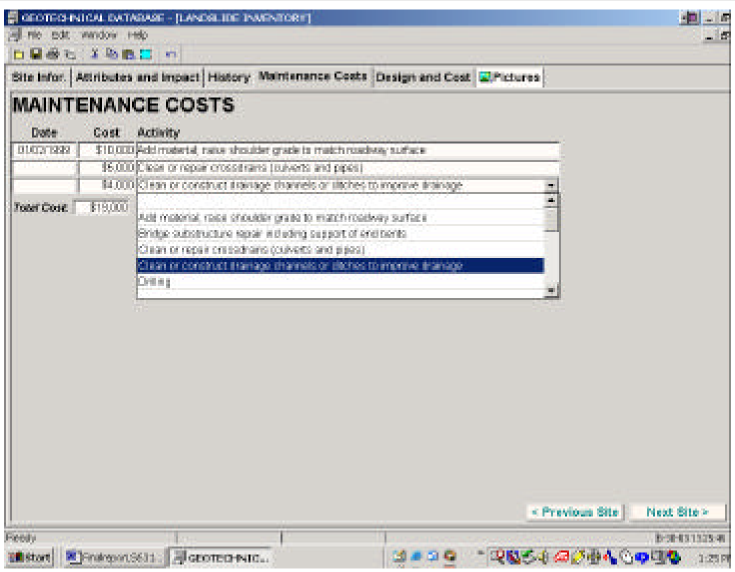


Figure 30. Data entry GUI screen for maintaining maintenance costs and actions performed.

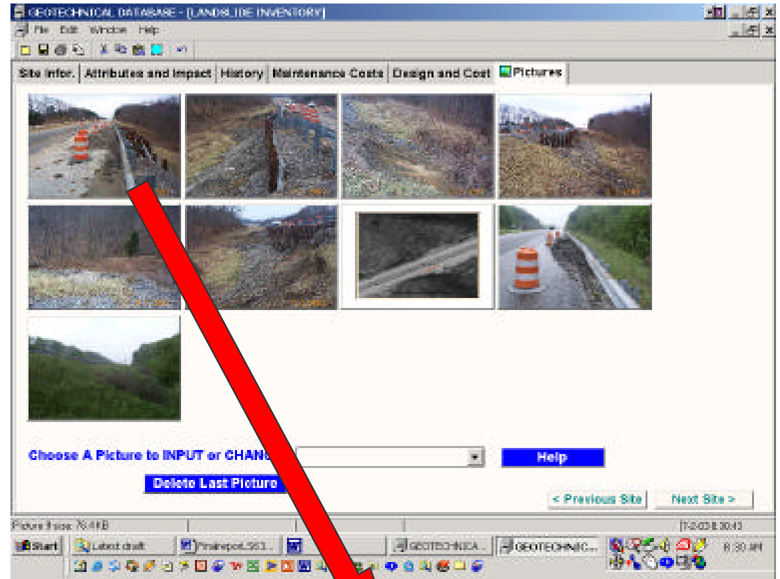


Figure 31. Views of a selected landslide.

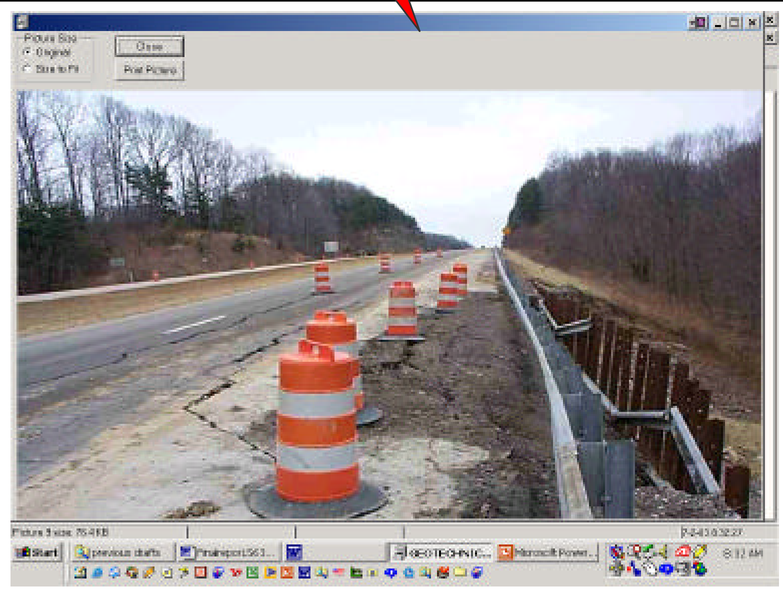


Figure 32. An enlarged view of one of the views of the selected landslide.

Some General Features of Highway Landslides in Kentucky

Highway Landslide Severity Ratings

The total number of landslides identified by the University of Kentucky Transportation Center (UKTC) at the time of this report is about 1,400. Location and identification of many of those landslides were obtained from listings obtained from the Cabinet's Highway District Offices. The Kentucky Transportation Cabinet listed another 851 landslides in their archives. Information pertaining to those landslides was very limited and mainly consisted of a route number, county name, milepost number, and an indication of whether the landslide had been repaired. Efforts were made to eliminate duplication of landslides in the Cabinet's database and the database of landslides compiled by UKTC. Site visits to several of the landslides listed by the Cabinet were made. According to records supplied by the Kentucky Transportation Cabinet, 587 of the 851 landslides, or about 70 percent, had been repaired.

About 250 of the 1,347 (18 percent) landslides compiled by UKTC reportedly were repaired. The status of each of the repaired landslides is indicated in the UKTC database. However, it is not always known precisely for each repaired landslide if the repair has been successful.

Severity ratings of the landslides compiled by the Geotechnology Section of the University of Kentucky Transportation Center at the completion of this report are shown in Figure 33. The majority (57 percent) of the highway landslides were assigned to the "C" category, which was described as "moderate movements, breaks in the pavement (occurrence over several years)." Generally, many highway embankments and foundations in Kentucky consist of clayey materials that tend to strain very slowly and prolong the time to the complete collapse of the embankment. About 24 percent of the landslides were rated "B," that is "(the landslide) is moving rapidly and requires constant maintenance (daily, weekly, monthly, etc.)." Approximately, 14 percent of the landslides were identified as "D," or minor slope failures affecting slope only. Highway landslides identified as "A," and described as "road is closed, one lane condition exists, buildings in danger, or safety concern," comprised about 4.6 percent of the surveyed landslides.

Distribution of Highway Landslides

The number of highway landslides identified in each Highway District of the Kentucky Transportation Cabinet is shown in Figure 34. The twelve highway districts of Kentucky are shown in Figure 11. Approximately 40 percent of the landslides (545) identified in the study are concentrated in district 6. This district is located in Northern Kentucky. A large portion of the district is situated in the Kope Geologic unit. Approximately 70 to 80 percent of this unit is composed of highly plastic clayey shale and about 20 to 30 percent limestone. The clayey shale of this unit slakes rapidly and breaks down when exposed to water. This action and the low shear strength of the shale have caused numerous major highway landslides in the area. The slopes in this area tend to weather rapidly and become very steep. Also, the hard and soft materials of the geological unit have caused major embankment compaction problems making it difficult to achieve good compaction. These conditions and the many streams (creating rapid drawdown and toe erosion) in the area create conditions conducive to landslides. A major portion (about 80 percent) of the highway landslides, Figure 35, are concentrated in four counties of district 6, which are Boone, Grant, Kenton, and Owen. Bedrock in these counties is mainly the Kope and Fairview Geological Formations. A map of district 6 showing the concentration of landslides is shown in Figure 36. In Bracken County, about 28 highway landslides occurred along State Route 8, which passes along the Ohio River.

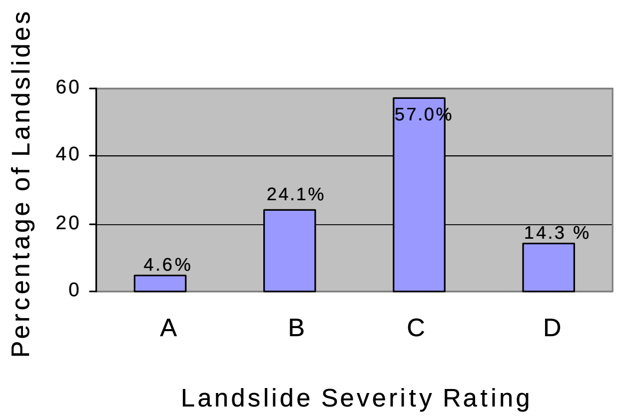


Figure 33. Severity ratings of highway landslides in Kentucky.

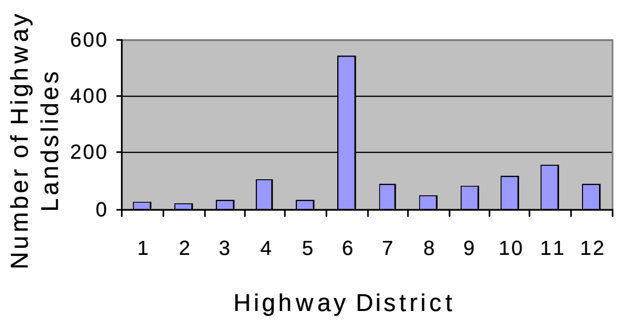


Figure 34. Number of landslides identified in each highway district of the Kentucky Transportation Cabinet.

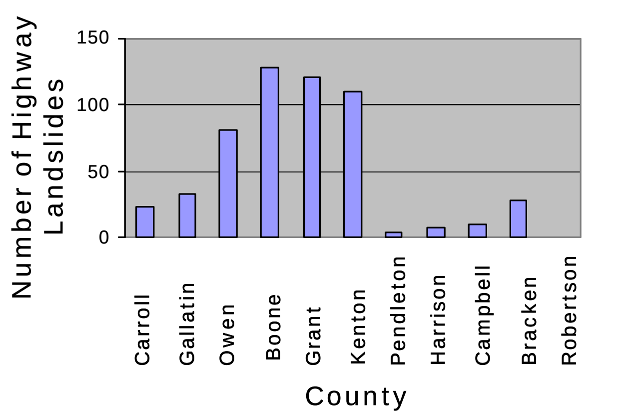


Figure 35. Number of landslides in the counties of Highway District 6.

As shown in Figure 37, about 77 highway landslides were identified (or reported) in Highway Districts 1, 2, and 3 of Western Kentucky. About 13 of those sites occurred on the Western Kentucky Parkway. About 137 landslides were identified in Districts 4 and 5 in Western Kentucky (Figure 38). About 13 of those sites were located on the Bluegrass Parkway. Approximately 140 sites were identified in Highway Districts 7 and 8, Figure 39 Locations of about 450 landslides in Districts 9, 10 11, and 12 are shown in Figure 40.

The occurrences of landslides in different physiographical regions of Kentucky were examined. The different physiographical regions of Kentucky are depicted in Figure 41. These include the Mississippi Embayment and Illinois Basin (Western Kentucky Coal Field) of western Kentucky. Geology of the Mississippi Embayment is composed of Quaternary and Tertiary deposits. The Western Coal Field is primarily Pennsylvanian age. Geologic age of a large area occupying the lower western-central portion of the state is primarily Mississippian. The eastern portion of the state is the referred to as the Appalachian Basin (Eastern Kentucky Coal Field) which is mainly Pennsylvanian age. The upper north- central part of the state is Ordovician and is referred to as the Bluegrass Physiographical Region. The Knobs Region forms a ring around the Bluegrass Region. Geological units of this area are predominately Silurian and Devonian.

As shown in Figure 42, only 17 highway landslides were identified in the Mississippi Embayment area. Soil units in this region contain large portions of sand

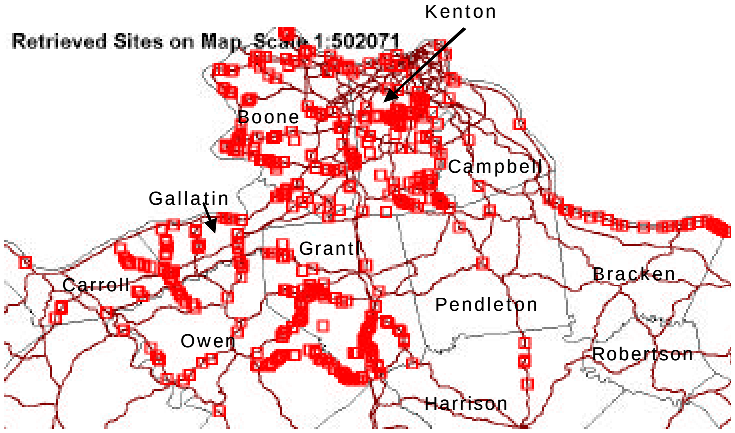


Figure 36. Locations of about 545 highway landslides in District 6.

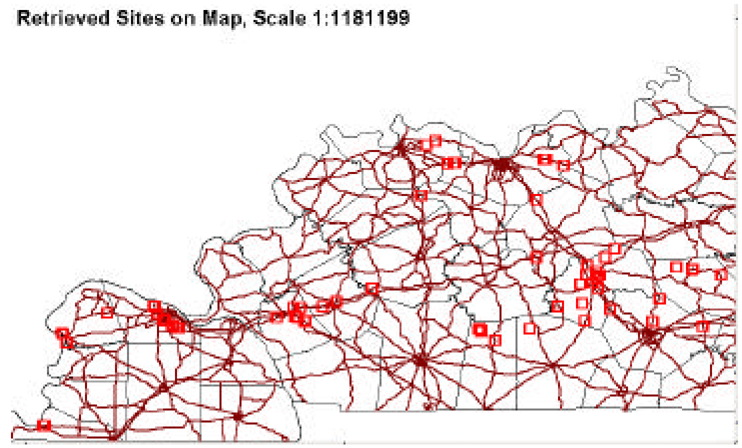


Figure 37. Locations of 77 highway landslides in Highway Districts 1, 2, and 3 of Western Kentucky.

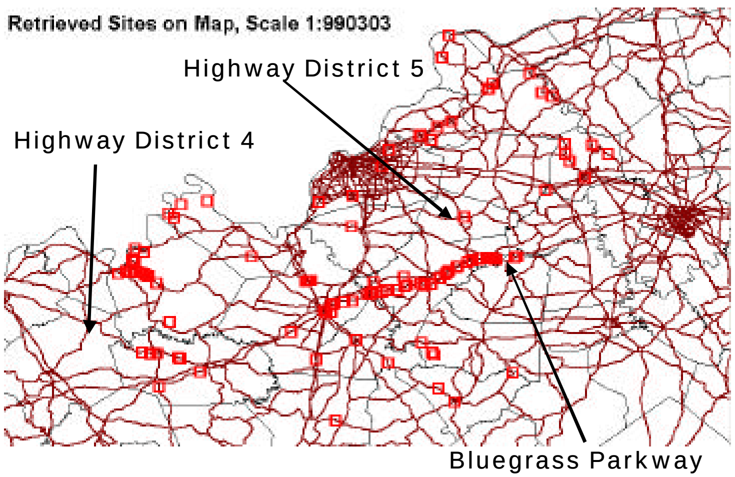


Figure 38. Highway landslides Districts 4 and 5 in North Central Kentucky.

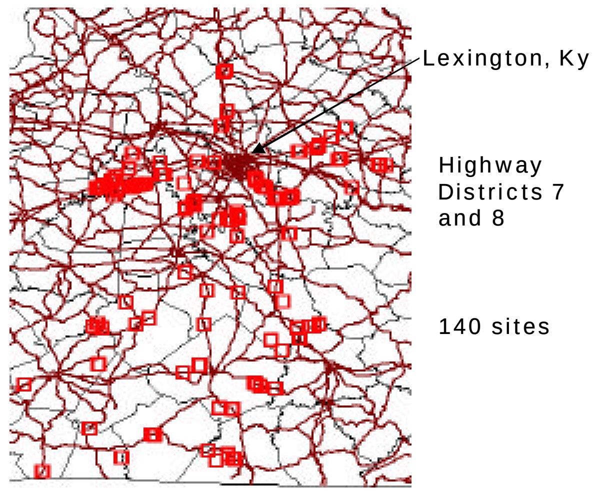


Figure 39. Highway landslides in Districts 7 and 8 in South Central Kentucky.

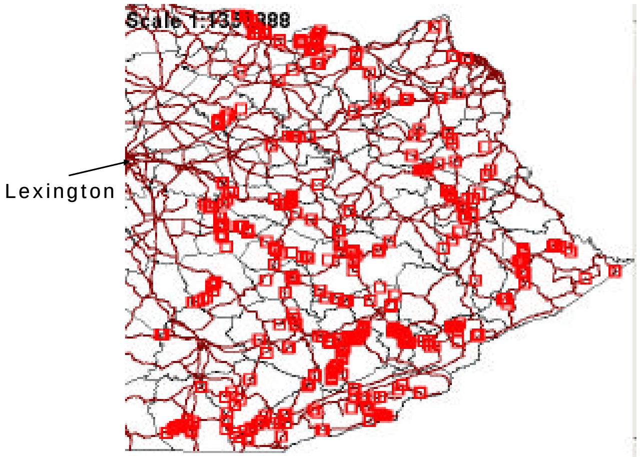


Figure 40 Highway landslides (about 450 sites) in Eastern Kentucky, Highway Districts 9, 10, 11, and 12.

and gravel with silt and some clay. Based on the Unified Soil Classification System, the soils are classified usually as CL-ML, ML, ML-Cl, GL-GM, SM, and SW-SM. These types of soils tend to have good shear strengths, which helps maintain good slope stability.

Highway landslides occurring in the Western Kentucky Coal Field are shown in Figure 43. Only about 41 highway landslides were observed in this region of the state. Rock units in this region consist of sandstone, shale, and coal. Soils in the region predominately are classified as clays-CL and some CH. The sandstones in the region used in road construction to form embankments have aided in maintaining some slope stability. However, the shales tend to cause instability in some cases.

About 107 landslides were identified in the Mississippian Plateau Region of the state, as shown in Figure 41 and 44. Rock units in this area consist of shale, limestone, and sandstone. The soils are predominately clays and have low shear strengths, which oftentimes leads to slope instability.

Highway landslides in the Eastern Coalfield are shown in Figure 45. Approximately 347 highway landslides were identified and located in the Eastern Kentucky Coal Field. Rock units in this region consist of shale, sandstone, and coal and are of Pennsylvanian Age. Typically, soils in this region are classified as clays (CL and some CH) and silty clays (Ml-CL). The large number landslides that occur in this region can be attributed to many factors, such as large embankments with steep slopes, and many streams located at the toes of the embankments that have caused rapid down and erosion of the toe of embankments. Another factor causing instability is the "damming" effect caused by side hill embankments that cause a gradual rise in the phreatic surface in the embankment. With a gradual rise in the water table, pore pressures in the embankments increase causing a decrease in effective stresses, which decreases the shear strength available to resist driving forces (Hopkins et al.1975, 1988)

Highway landslides occurring in the Knobs region, which forms a ring of small hills around the Bluegrass Physiographic Region is depicted in Figure 46. Although this Region is much smaller than other physiographic regions of the state, numerous landslides have occurred in the Knobs Region. Factors cited above are typically of the causes of the numerous failures (107) identified in this region. Weak shales of the Crab Orchard Geological Unit have frequently been involved in many of the failures.

Numerous highway landslides have occurred in the Bluegrass Physiographic Region, Figure 47. Approximately 50 percent of the highway landslides in Kentucky occur in this region — about 654. The majority of the landslides in the northern portion of the physiographical region mainly occur in four counties –Boone, Grant, Kenton, and Owen. Numerous landslides occur in roadways that were built through and with weak shales of the Kope Geological Unit (Ordovician Age).

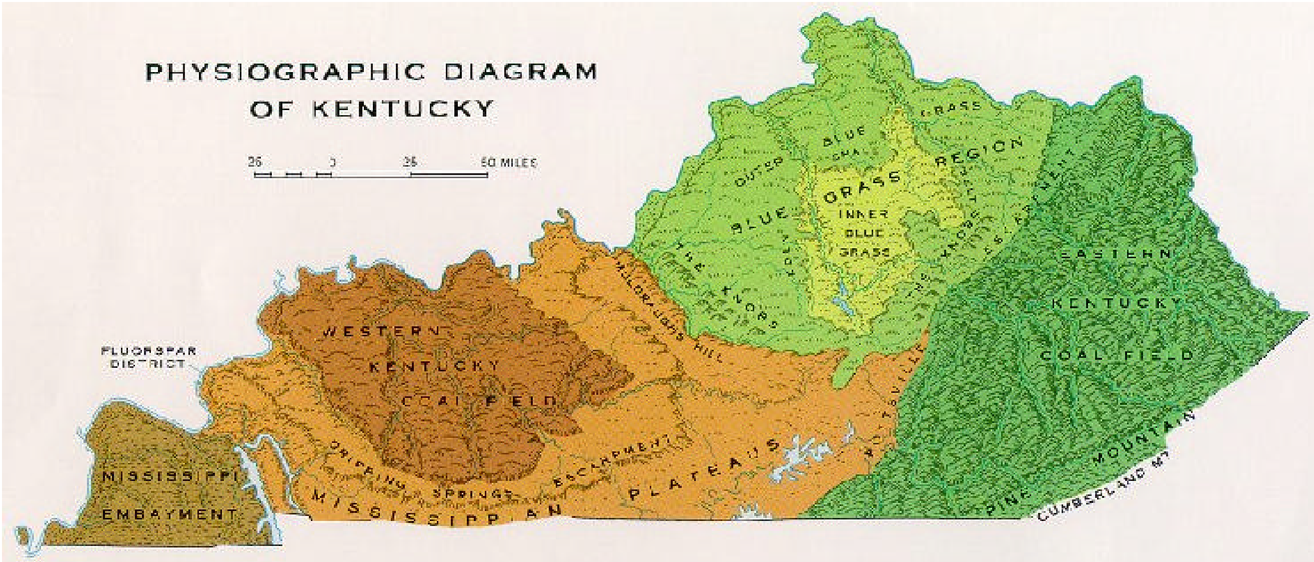


Figure 41. Physiographical Regions of Kentucky (Map obtained from the Kentucky Geological Survey).

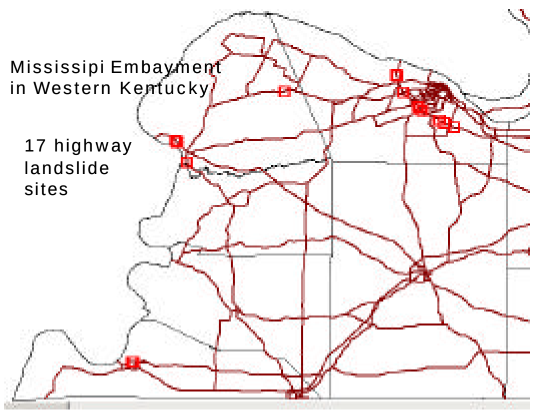


Figure 42. Highway landslides in the Mississippi Embayment area of Kentucky.

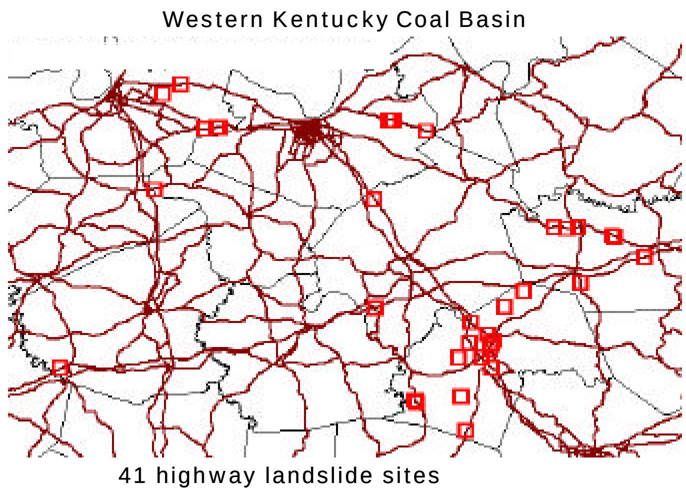


Figure 43. Highway landslides in the Western Coal Field.

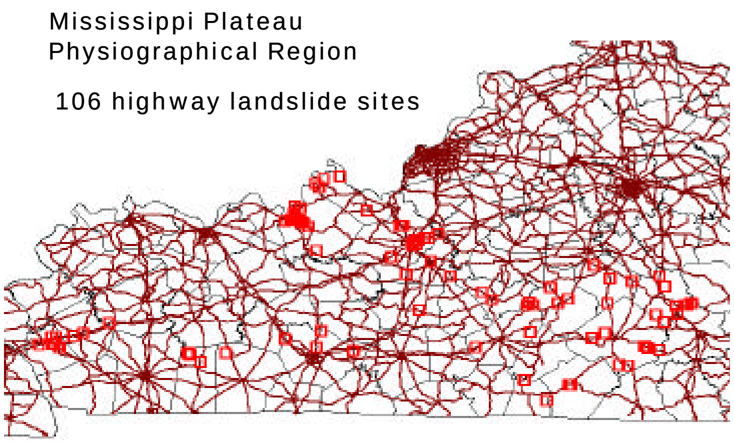


Figure 44. Highway landslides in the Mississippian Plateau Region.

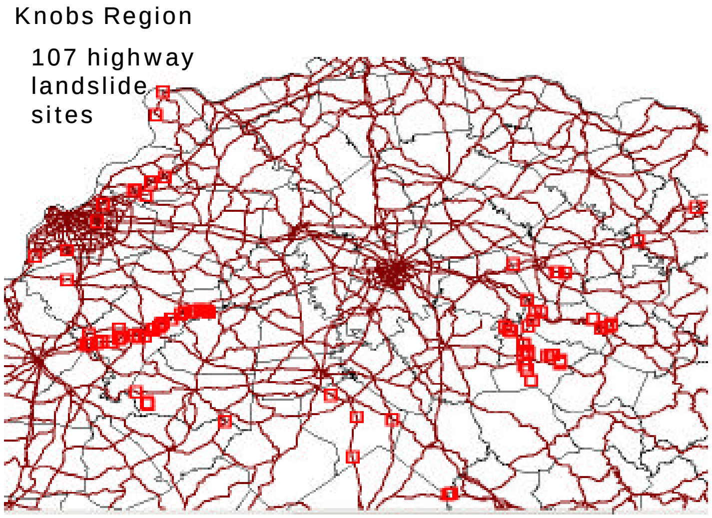


Figure 46. Highway landslide sites in the Knobs Region.

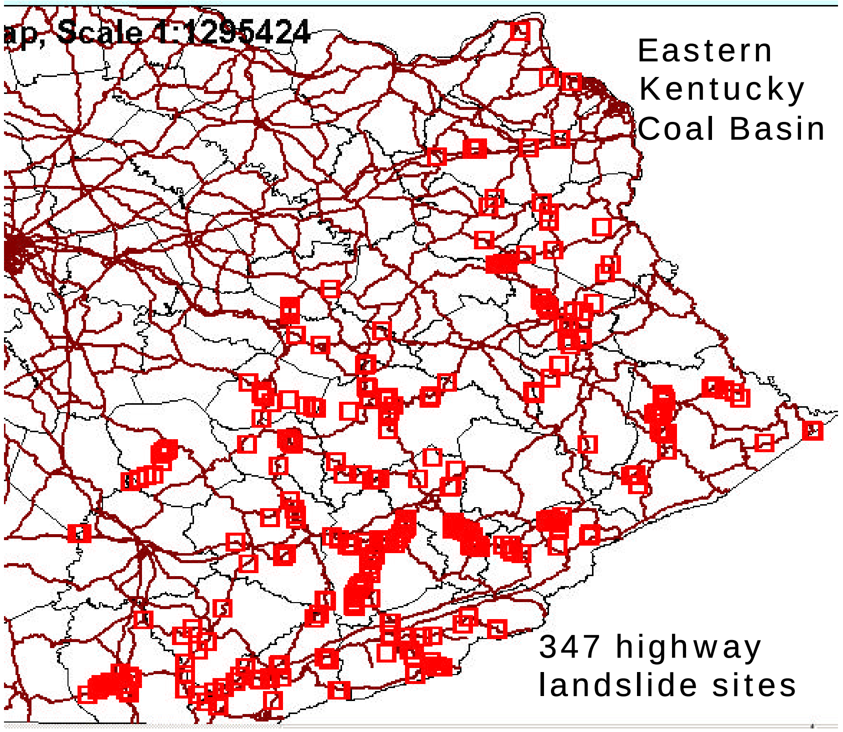


Figure 45. Highway landslides in the Eastern Kentucky Coal Field.

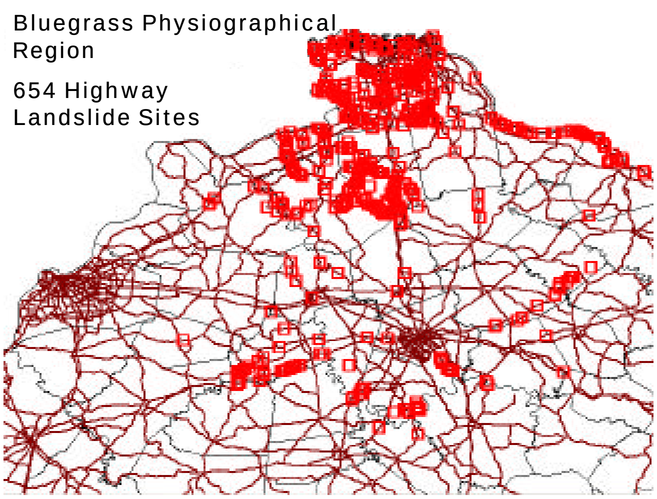


Figure 47. Highway landslides in the Bluegrass Physiographical Region.

This unit contains approximately 20-30 percent of limestone and about 60 to 70 percent shale. The shales of Kope Geological Unit slake rapidly when exposed to water and breakdown into very weak soils. A major problem in constructing embankments of shale-limestone mixtures is the difficulty in achieving proper compaction because of a failure in breaking down the hard limestone-soft shale mixture. The lack of good compaction has caused numerous failures on Interstates 71 and 75 that pass through this region. Because the shale-limestone were loosely compacted, large voids occurred in the embankments. As the phreatic surface gradual rose in the embankments, the soft shales degraded into soil particles causing large settlements and eventually instability (Hopkins and Beckham 1998). Many of the embankments in this region are side –hill-fill situations. Depth to bedrock in this area is very shallow and usually measures openly a few feet. Typically, a very weak layer of weathered shale/soil exists near the top of the rock unit. Shear surfaces of the embankment failures often time pass through the weak layers.

Repair Cost Estimates

As the height of a landslide increases the cost of repairs generally increases (Hopkins et al 1988). For instance, data compiled by Hopkins in 1988 and based on repair costs of about 35 landslides showed that the approximate cost of repairing a landslide measuring 20 feet in height was about 200 dollars per linear foot of the landslide. When the height of the landslide was about 80 feet, the cost of repairing the landslide was about 1,100 dollars per linear feet. A very approximate formula for estimating the repair cost (based on early eighties cost data for berms/flattened slopes) is

Landslide Repair Cost ? (Cost per Linear Foot x Ht. of Slide)(length of Slide)(CPI) and (1)

Landslide Repair Cost ? (15Ht. - 100)(length of Slide)(CPI) (2)

where CPI is the consumer price index –base year is about 1982. Considering inflation since about 1982 and using the average Consumer Price Index, the costs in 2003 would be approximately 400 dollars and 2200 dollars, respectively.

For a landslide measuring 100 feet in length and about 20 feet in height, the estimated repair cost would be about 76,000 dollars. A landslide measuring 80 feet in height and 1200 feet in length would require an estimated cost of about 210,000 dollars. These costs escalate as the length of slide increases. If the lengths of slides in the examples above were 300 feet, then the estimated repair costs would be 228,000 and 630,000 dollars respectively. Based on a Consumer

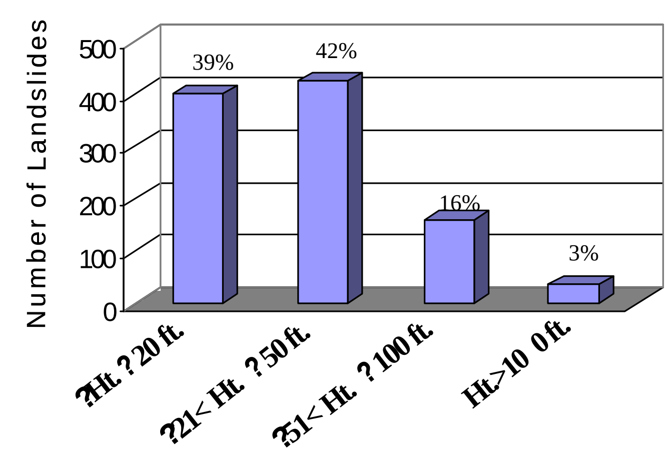


Figure 48. General heights of highway landslides in Kentucky.

Price Index of about 2.0—1984 to 2003—the landslide in the example would costs 152,000 and 420,000 dollars, respectively, in 2003 for the first case. The costs in 2003 for the second case would be 456,000 and 1,260,000, respectively.

Different categories of heights of highway landslides compiled by UKTC are shown in Figure 48. The height of about 39 percent of the highway landslides is equal to or less than 20 feet while the height of about 42 percent of the landslides was greater than 21 feet or less than or equal to 50 feet. The height of about 81 percent of the landslides was less than or equal to 50 feet. The height of about 16 percent of the landslides ranged from 51 to 100 feet while the height of about 3 percent were greater than 100 feet.

Distribution of the lengths of the landslides is shown in Figure 49. Lengths of about 45 percent of the landslides were 200 feet or less. About 33 percent of the landslides had lengths greater than 300 feet, but less than or equal to 500 feet. Lengths of about 22 percent of the landslides were greater than 500 feet. Total length of all landslides was 423,030 feet.

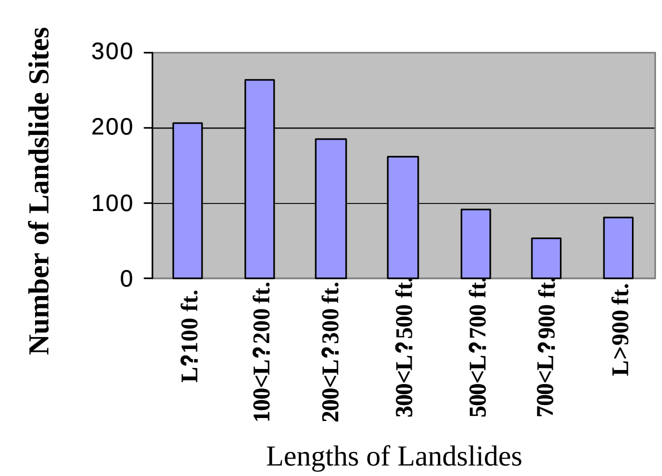


Figure 49. Numbers of landslides in specific length categories.

Data in Table 1 is a very approximate attempt to estimate the amount of money that would be needed to repair the highway landslides compiled by UKTC. A number of assumptions were made. Based on past cost data (Hopkins et al 1988) and a relation between unit repair cost per linear foot of landslide and height of landslide slope, an attempt was made to obtain a very approximate cost to repair the highway landslides compiled by UKTC. The estimated cost is shown in Table 1. Average heights of the landslides were estimated from the data presented in Figure 44. For the four categories of slope height, values of about 15, 38, 68, and 125 feet were assumed. Based on the percentages shown in Figure 43, the lengths of the slide for each height category was estimated, as shown in Table 1. Using the average heights and Equation 2, the estimated costs for each height category was made. For example, for the height category, 51 to 100 feet, the costs were estimated as

$$Estimated \quad Cost\ ?\ (15xHt\ ?\ 100)\frac{dollars}{ft}CPIx0.16x423{,}030\,ft\ =$$

$$Estimated \quad Cost\ ?\ (15x68\ ?\ 100)\frac{dollars}{ft}(2.0)x0.16x423{,}030\,ft\ ?\ 114\,million\ dollars.$$

Based on information collected during the survey of landslide sites in Kentucky, railroad steel tracks have been used often in an attempt to halt movement of the landslide by forming a retaining wall structure. Sometimes the soil behind the retaining structure is excavated and backfilled with rock. Some type of cribbing, such as railroad wooden ties, or concrete panels, may be used to prevent spillage of the rock through the railroad steel tracks. Frequently, holes are drilled through the embankment and several feet into bedrock. By inserting the steel rails into bedrock, a cantilever structure is created.

Remedial measures had been attempted at about 282 landslide sites (of 1448 sites) based on the data compiled by UKTC. At about 180 of those sites, a railroad steel retaining structure was used. At about 175 sites of the 180 sites, based on notes and comments in the database, the railroad steel tracks had been placed in drilled holes into bedrock. At five sites, the railroad steel had been driven. At approximately 37 percent of the sites, the embankment height was less than or equal to about 20 feet while, at about 63 percent of the sites, the embankment height was greater than about 20 feet. Status of the repaired landslides is not precisely known and this information needs to be collected in the future.

Table 1. Estimated costs to repair landslides compiled by UKTC.

Approximate Average Height (Feet)	Percentage of landslides in Height Category	Total Length of all Landslides (Feet)	Length of Landslides for Each Height Category (Dollars)	Estimated Unit Cost per Linear Foot of Landslide[1]	Approximate Landslide Estimated Repair Costs (Million Dollars)
?20	39	423,030	164,982	400	66
21<Ht. ?50	42	423,030	177,673	880	156
51<Ht. ?75	16	423,030	67,685	1,690	114
Ht.?100	3	423,030	12,691	3,550	45
				Total estimated cost =	381

1. Unit Cost Landslide = (15)(Ht of Landslide)-100)(CPI). The unit cost is based on a relation between unit cost of repairing a landslide using berms/flattened slope in about 1982 and height of landslide slope. The unit cost of 1982 was adjusted to 2003 using the Consumer Price index –about 2.

Rock Slope Database and Management System

Effective management of rock slope problems requires a system that will help identify potentially hazardous sites where rock fall may occur. Also, the system should be simple and clearly identify the important parameters that largely controls the rock fall potential of a cut slope. A rock fall hazard rating system (RHRS), developed by the Oregon Department of Transportation for the Federal Highway Administration, met the conditions cited above.

Details are given elsewhere (Pierson and Van Vickle 1993; Pierson 1993). The rating system provides a rather simple and uniform means of identifying potentially dangerous rock fall slopes and a method for developing a priority list of sites where protective measures, or repairs, may be needed.

When using the RHRS approach, rock slopes are initially classified, visually, for the potential of falling rocks entering the roadway. Rock slopes assigned to the classification, "A," have high potential for falling rocks entering the roadway, as illustrated by the slope in Figure 50. A "B" classification indicates a moderate chance for rocks entering the roadway. Figure 51 is a view of a typical "B" slope. Slopes with a small chance of falling rocks entering the roadway are classified as "C", as illustrated in Figure 52. A large number of slopes on a selected route can be surveyed quickly by merely driving the route and assigning each slope to one of the three categories. Historical information can be used in the preliminary classification. RHRS is a proactive way to address problematic rock slopes and is a very useful tool to assist in allocation of funds to repair hazardous rock cuts (Pierson and Van Vickle, 1993).

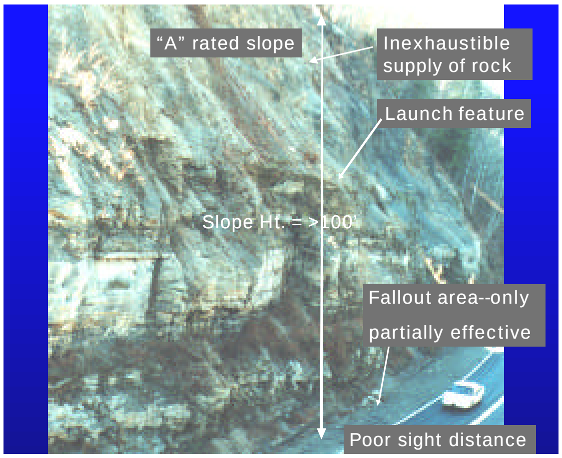


Figure 50. Example of an "A" rated slope.

Figure 51. Example of a "B" rated slope.

After obtaining preliminary ratings, slopes that were assigned (subjectively) to A and B categories are rated numerically using the RHRS approach. Detailed numerical ratings of rock slopes are based on 12 categories, or attributes. These include slope height, ditch effectiveness, average vehicle risk, percent of decision sight distance, roadway width, geologic character (Case 1--rock jointing and friction between joints) or geologic character (case 2--differential erosion features and differential erosion rates), block size or volume, climate, and rock fall history. The system provides a good means of assessing the risk associated with a site. Scoring graphs, based on an exponential scoring system, have been established for each category.

Figure 52. Example of a "C" rated slope (after Pierson and Van Vickle, 1993).

All components of the RHRS approach have been programmed into the Kentucky

Geotechnical Database using Graphical User Interface (GUI) screens. In cases involving scores between set points, the program provides the range of scores that can be entered and controls allowable values the user can enter. Total score is automatically tabulated after the user has entered all data for all parameters. Spaces are available to enter comments relative to each category or the rock fall site. Any comments entered are displayed on printed reports. Preliminary surveys of about 10,000 rock slopes on interstates, parkways, primary routes, and some secondary routes in Kentucky were surveyed. Approximately 2,400 rock slopes assigned to categories, "A" or "B," were rated numerically. Latitude and longitude of each site were obtained using GPS equipment. Also, photographs of each site were obtained. All data, including electronic photographs have been stored in the database.

A rock slope is considered a site in the database. Site information includes county, route, mile point and station if known. Space is also available to enter location and description comments. Rock slope data for slopes is entered to the database by use of graphical user interface screens. A GUI screen, including tabs for entering data for rock slopes, is illustrated in Figure 53. The rock slope portion of the database has been described in detail in a companion report (Hopkins et al 2003).

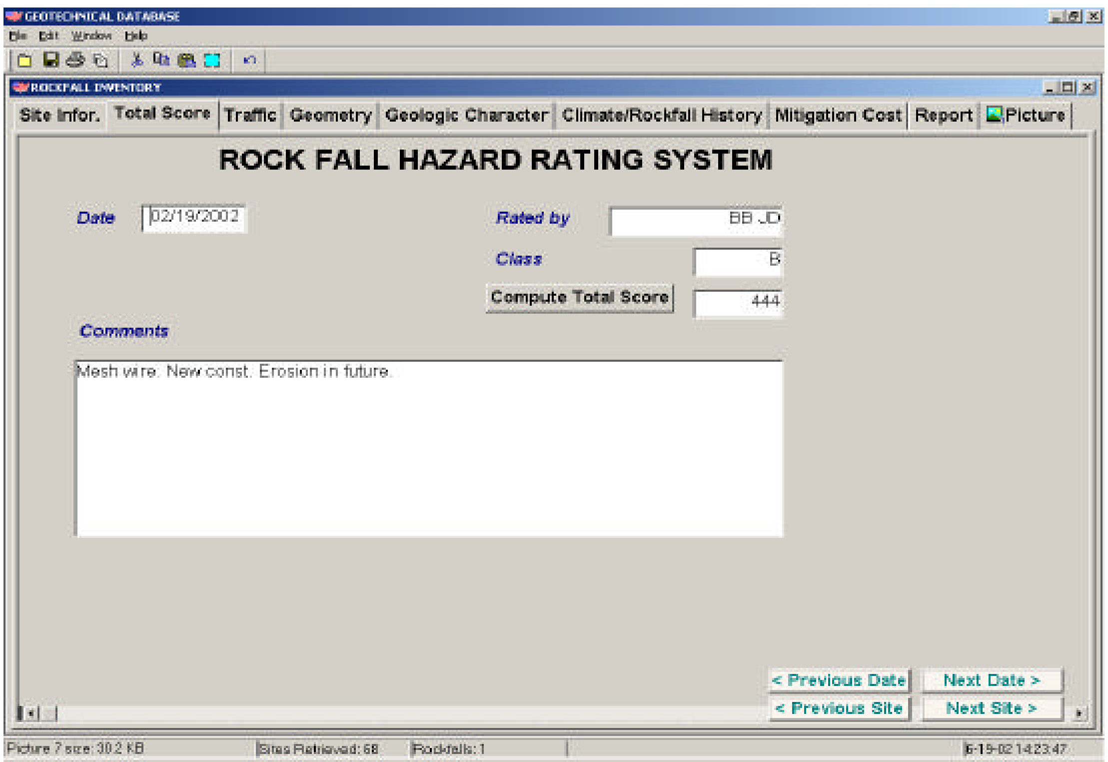


Figure 53. GUI screen for entering rock slope data.

Structures

Another major component of the database is structures (see Figure 19). Structures include bridges, buildings, culverts, dams, drainage units, pavements, utilities, and walls. Access to and data entry for structures can be obtained using the dropdown list on the site graphical user interface, as illustrated in Figure 54.

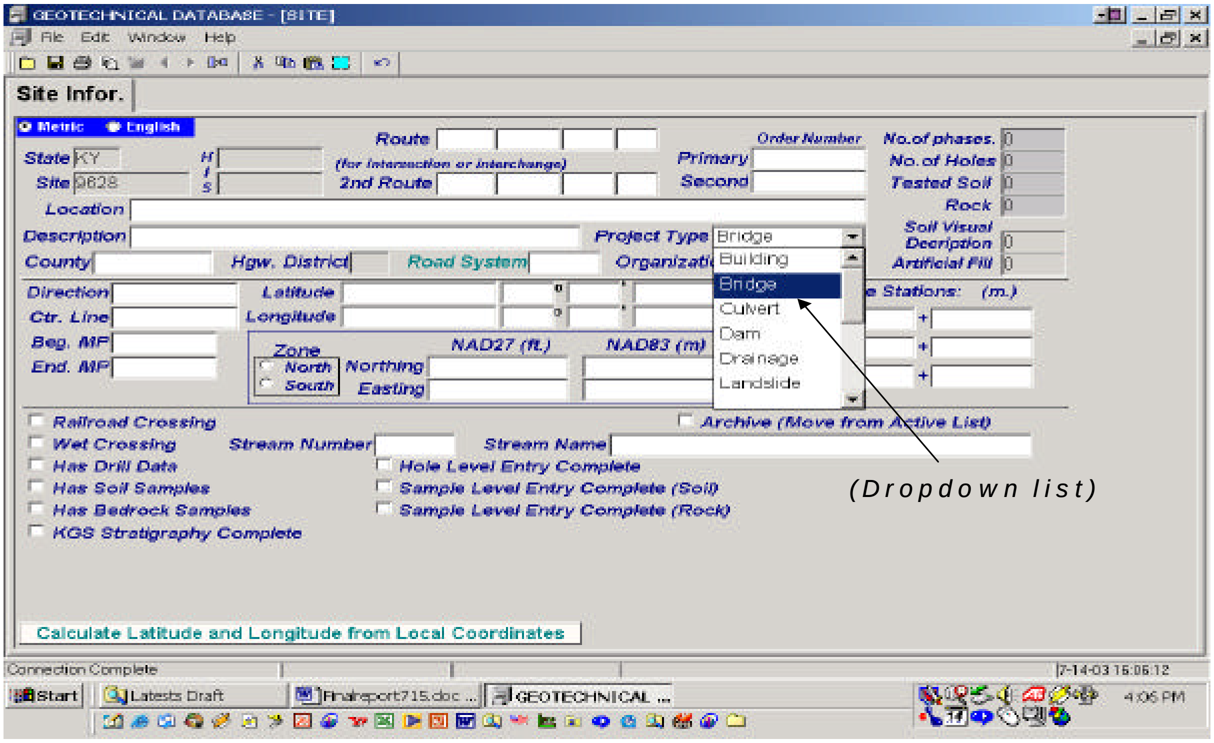


Figure 54. Method of accessing structures using a dropdown menu on the Graphical User Interface for entering site information.

Soil and Rock/Hole Engineering Database

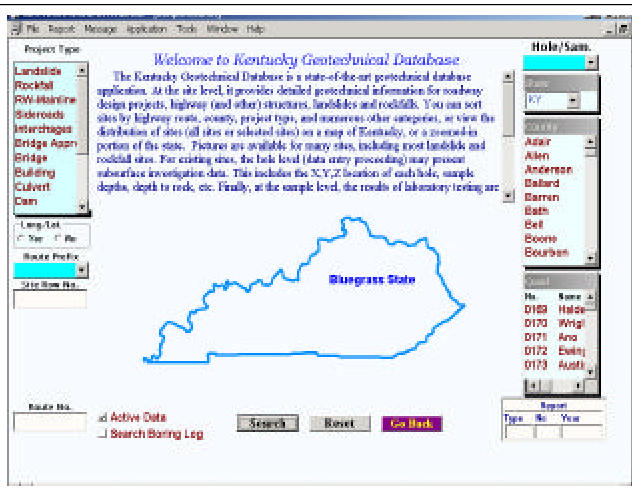


Figure 2

Development of this portion of the database consists of two parts. The first portion was designed for entering historical soil and rock engineering data (Figure 55). Soil and rock sample data includes such information as project number, station number, depths, or elevations, of samples, Latitude and longitude, or state plane coordinates, can also be entered. If state plane coordinates are entered, than built-in algorithms automatically convert the values to latitude and longitude. Other sample entries include such data as strength test values, Atterberg limits, grain-sizes, specific gravity, soil classifications, laboratory and field data, bearing ratios, moisture-density relations, Rock Quality Designation (RQD) values, slake-durability indices, jar slake values, soil and aggregate resilient modulus, and consolidation. Hole locations can be retrieved and plotted on maps, as illustrated in Figure 56. Any area on the map in Figure 56 can be enlarged using the zoo sho cap geo pro the des as to ous he nto be

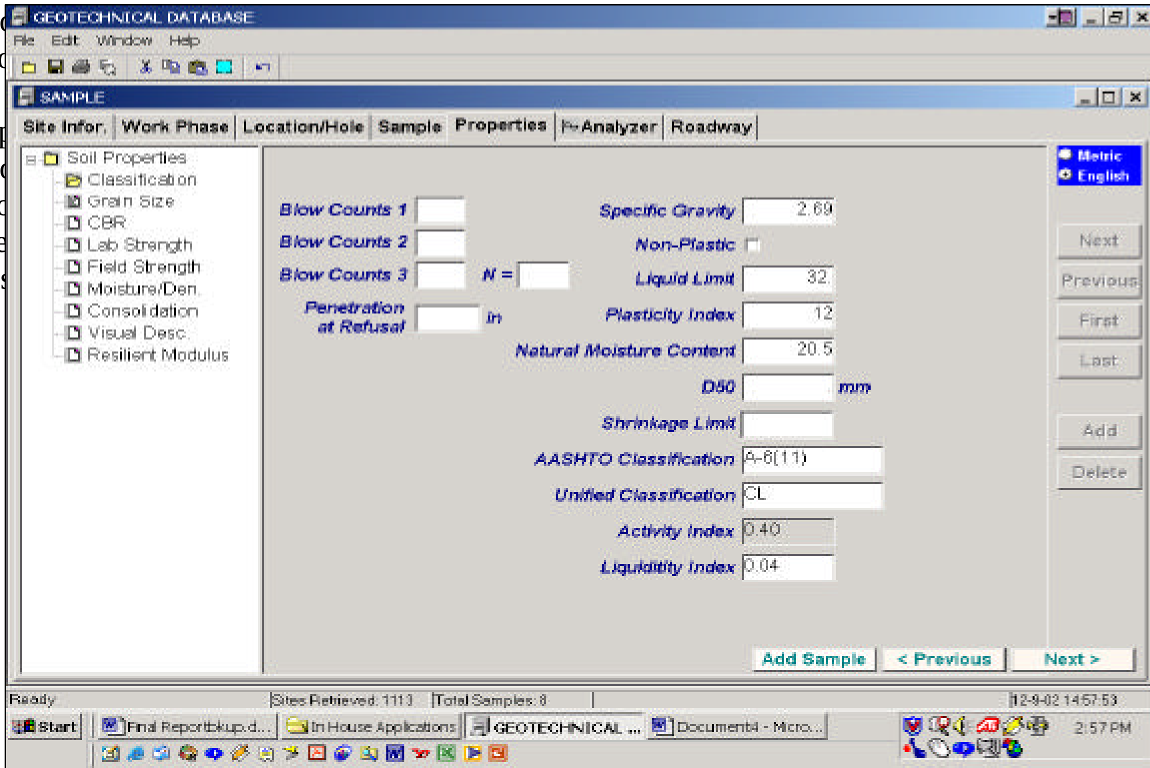


Figure 55. GUI screen for entering engineering and geology data for soil samples and hole data.

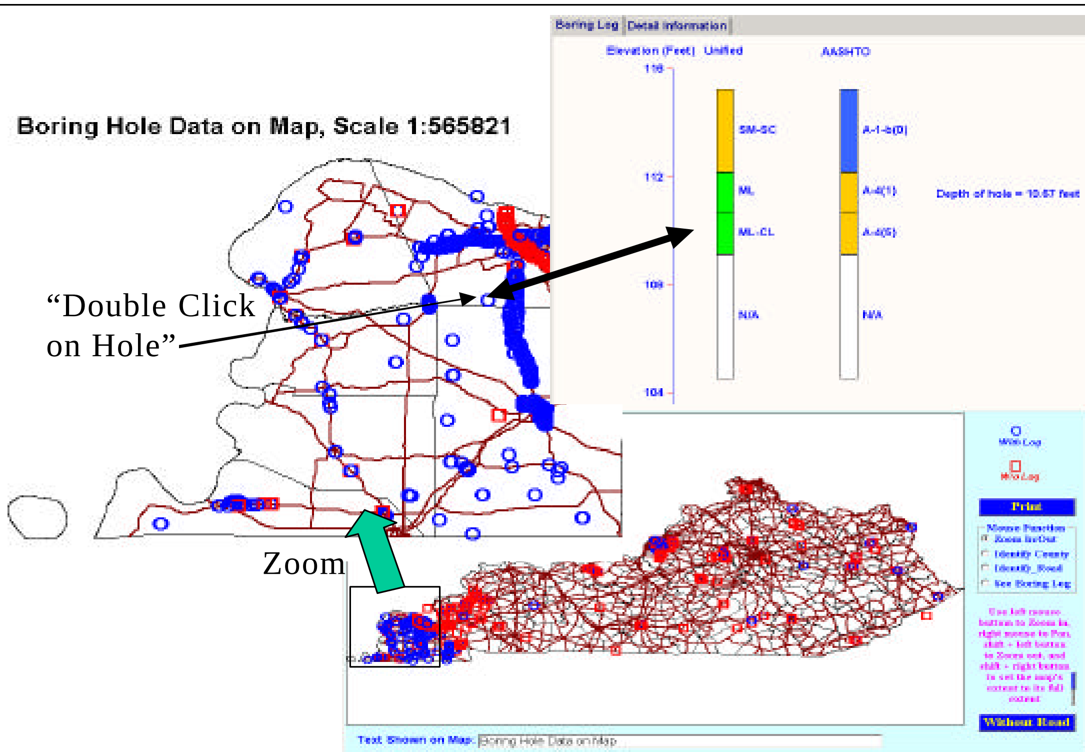


Figure 56. Illustrations of plotted hole locations on a map of Kentucky, the zoom feature, and an example soil profile.

Secondary Components of Database

Secondary components of the geotechnical database include a series of statistical and data regression analyzers, engineering software applications, and visual features, which include electronic photographs and map displays. These components have either been programmed by the authors or other software has been embedded into the database. Another planned secondary feature will allow the storage and reduction of field geotechnical instrumentation data. The secondary components are described in more detail below.

Statistical and Regression Analyzers

To avoid the inconvenience of having to download data to other programs and perform some type of analysis, the database contains a collection of statistical and regression analyzers developed by the authors. These software programs can be used while “on line “ with the database. This feature allows the refining of selected raw data in the database for the purposes of supplying reliable data for preliminary, or in some cases, final engineering designs and for obtaining correlations among different types of data. Functions of this portion of the database

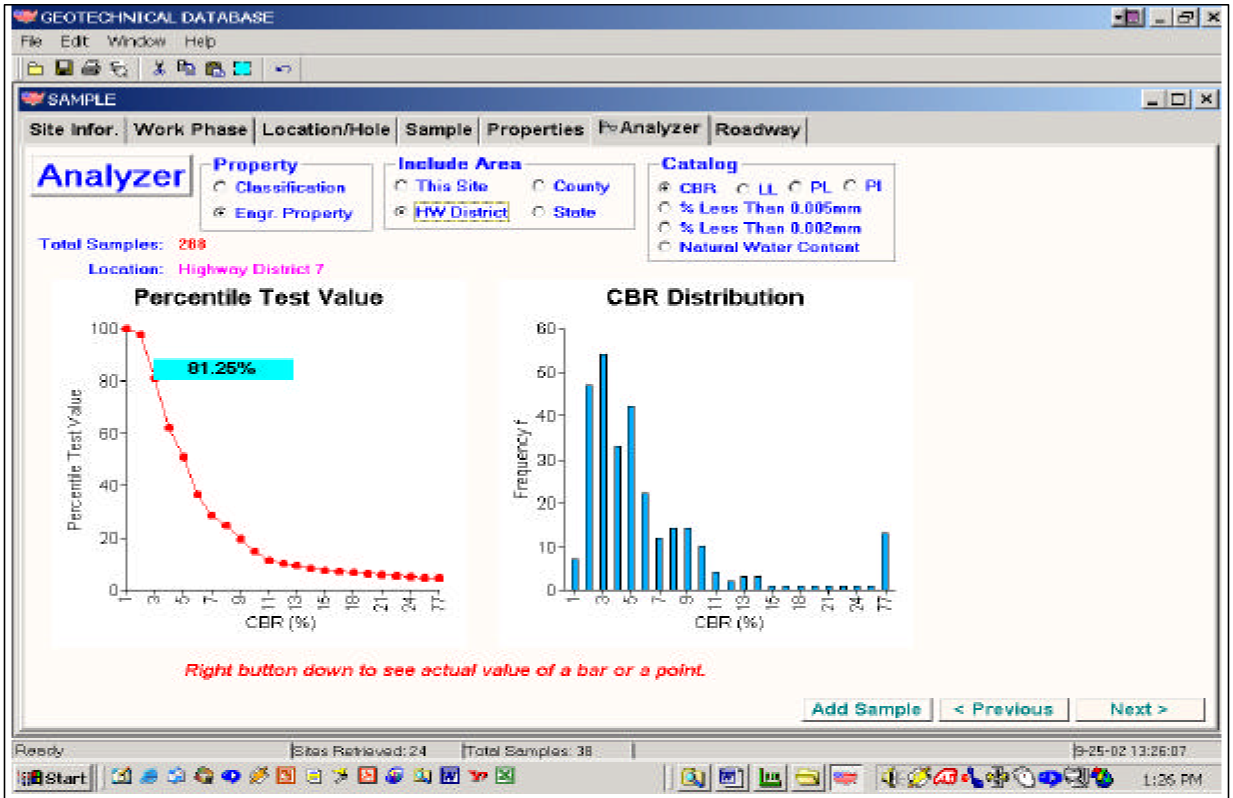


Figure 57. Use of statistical analyzers to determine the relationship between percentile test values and laboratory CBR values of Highway District 7 in Kentucky.

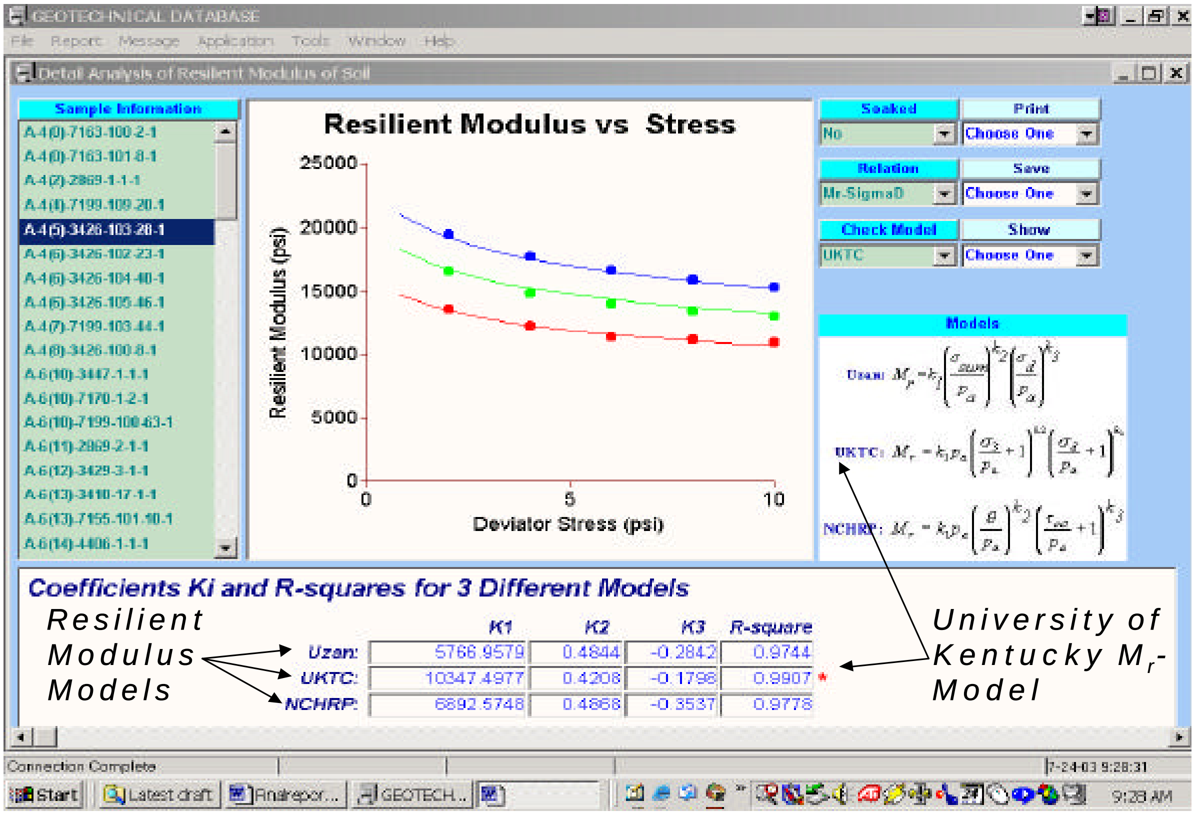
analysis are to map out the distributions of all type of data and construct their internal correlation. The results can be presented in both tabular and graphical format.

Currently, data in the Geotechnical Database includes landslide, rock fall, and soil and rock engineering and geologic information. First, programs in the analysis section will present the distribution of those data across the state or any selected and particular location. For instance, data for a selected site, highway district, county, or the state can be retrieved and analyzed, as shown in Figure 57. In this example, the user is interested in CBR values of soils in a selected highway district in Kentucky. All CBR values that exist in the database for the selected county are retrieved and displayed as a function of percentile test value. For a preliminary pavement design analysis, the user might select the CBR at the 85th percentile test value (Yoder 1969, 1975). Other situations exist where this approach could be useful. For instance, the approach could be used when very small design jobs arise, such as a new ramp off a roadway and it is not very economical to obtain samples for CBR testing. The CBR value at a selected percentile value could be used for designing pavement thickness of the ramp. Analyzers have also been included in the program for examining the distribution of different soil and rock types, or classes, of a selected area, as well as other engineering properties. Distributions (and statistics) by soil class—AASHTO Soil classifications and Unified Soil Classifications—can be displayed for any selected area, or highway corridor. Knowledge of predominant soil classifications of an area is invaluable for assessing general construction problems that may arise. For example, if the predominant soil classification is known, then the designer, and contractor, can select the most suitable compaction equipment for that area. For preliminary construction cost estimation, this is invaluable. Secondly, methods for analyzing and disclosing how different types of data are related are included. For example, analysis can present how rock falls and landslides relate to the type of soil and rock, as well as their properties. Stored regression analyzers yield correlation, or data fit, between different soil parameters. Finally, the large amount of stored data in the Kentucky Geotechnical Database is very useful for research purposes.

Conventional models of stress-strain, consolidation, and modulus-stress will be available for performing data analysis. When choosing any model for soils in a particular location, programmed procedures of the analysis section will show the coefficients for the model selected. For instance, models for predicting the resilient modulus (AASHTO 1992, 1993; SHRP 1989) of any type of soil have been programmed into the database. When the AASHTO soil classification of a soil is known, the resilient modulus can be determined by using the GUI screen illustrated in Figure 58. The user clicks on a soil classification and the three regression models and coefficients appear as shown at the bottom of Figure 58. Various resilient modulus models have been programmed into the database. Included in the models is a model suggested by Ni et al (2002) and Hopkins et al (2002). However, mathematical models suggested by the National Cooperative Highway Research Program (NCHRP 2002) and Uzan (1985) have been included in the database applications. Although originally two-dimensional models were included, these models were dropped from the database because of limitations of those models. A view of the regression plane, based on the authors' model, for a typical Kentucky soil is illustrated in Figure 59.

Engineering Applications

Applications in the Geotechnical Database are a collection of computer programs for performing engineering designs of geotechnical structures and for obtaining selected designs in geotechnical engineering. Routine designs such as pavement, foundation, retaining wall, and slope stability are programmed into the Geotechnical Database. In some instances, the programmed computer procedures strictly follow published procedures, standards, regulations, or mathematical algorithms. In other cases, the authors have developed customized computer programs.



	K1	K2	K3	R-square
Uzan:	5766.9579	0.4844	-0.2842	0.9744
UKTC:	10347.4977	0.4208	-0.1798	0.9907 *
NCHRP:	6892.5748	0.4868	-0.3537	0.9778

Figure 58. Method of selecting coefficients of various resilient modulus models.

Examples of programmed procedures and graphical user interfaces include the 1993 AASHTO[1] and 1981 Kentucky[1] flexible pavement design procedures, as shown in Figures 60 and 61, respectively. By storing these programs in the database, on-line analysis and designs can be generated. This is very useful in performing preliminary, as well as final designs. The graphical user interface of the computer program illustrated in Figure 60 includes a cost analyzer (Figure 62), which can be used to examine and compare the costs of different pavement design sections composed of pavement layers of different thickness.

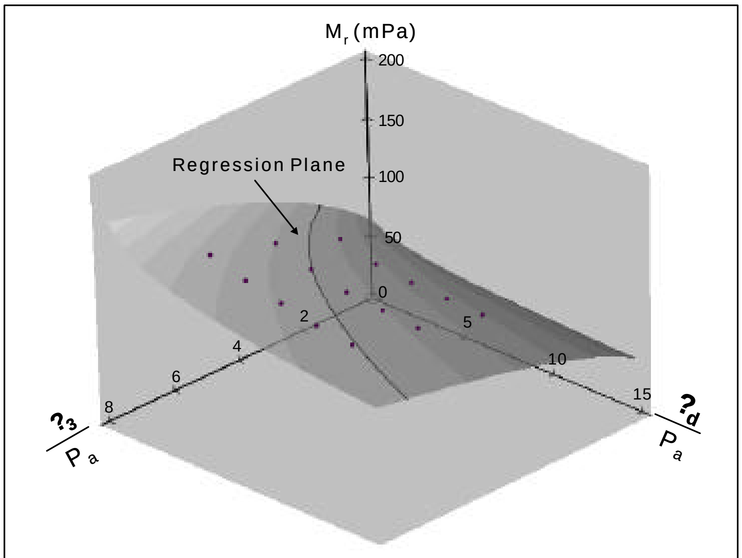


Figure 59. Least square regression plane.

Another program in the applications' section of the database can be used to analyze and design retaining walls constructed of driven,

[1] Computer programs developed by Charlie Sun, Bixian Ni, and Tommy C. Hopkins of the University of Kentucky Transportation Center, Geotechnology Section in 2000.

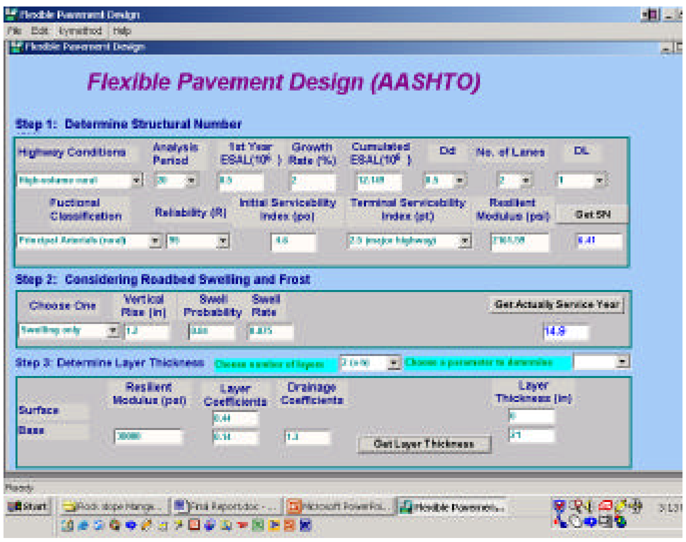


Figure 60. GUI data entry screen for designing the thickness of an asphalt pavement using the AASHTO Design Procedure (1993 Guide).

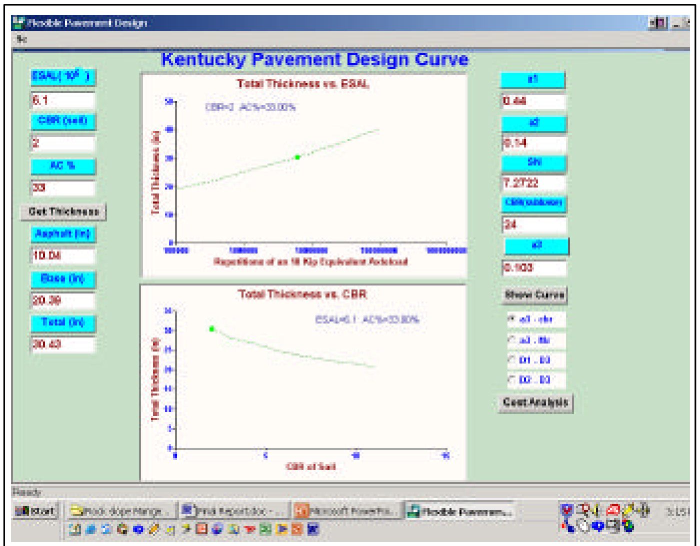


Figure 61. GUI data entry screen for designing the thickness of an asphalt pavement using the 1981 Kentucky Design Procedure.

or drilled-in railroad steel rails, Figures 63 and 64, and back filled with soil, or lightweight materials. The notion of developing this program for the database occurred after analyzing some 1,400 landslides on Kentucky's highways and finding that in at least twenty percent of those cases retaining walls constructed of railroad steel rails had been driven, or fixed into bedrock, in an attempt to halt highway landslide movement. The interactive, data entry GUI screen for determining the factor of safety of a rail piling retaining structure is illustrated in Figure 65. Unit weight of any material may be inserted by merely entering its numerical value. Lightweight materials, such as geofoam, "red dog," lightweight aggregate, and cinders from coal-fired, power plants may be used in the program. Algorithms used in the program were derived and developed to account for the use of lightweight backfill materials.

In many cases, railroad rails used as pile retaining structures have not worked. By making a design program available, highway district personnel can quickly develop a proper design for use of this landslide repair technique. In many observed failures, the technique did not work when the backfill was greater than about twenty feet, when the steel rails were not anchored into bedrock, or the soil backfill flowed through the rails. When any of those conditions prevail, state geotechnical engineers do not recommend using steel rail retaining walls. However, the database design program now identifies additional cases where this correction method, which is favored by many district operations (maintenance) offices, might be successful. By using lightweight backfill, and particularly where the rail piling can be anchored into bedrock, slides approaching heights of 18-20 feet, or slightly greater, could be repaired. The amount of lightweight backfill required to achieve a safe design (or a selected factor of safety) is determined from the computer program. District personnel and geotechnical staff of the central office can review the solution simultaneously.

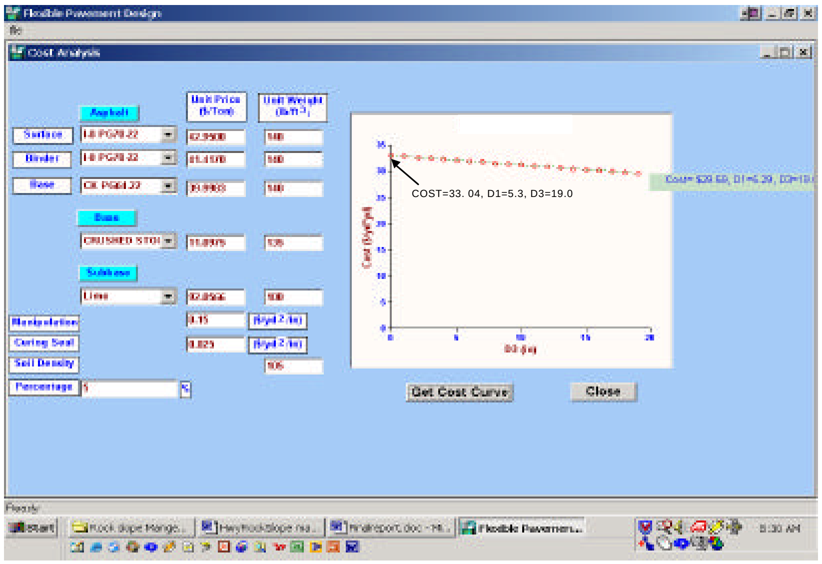


Figure 62. GUI screen for performing cost analyses of flexible pavements with and without chemical stabilization.

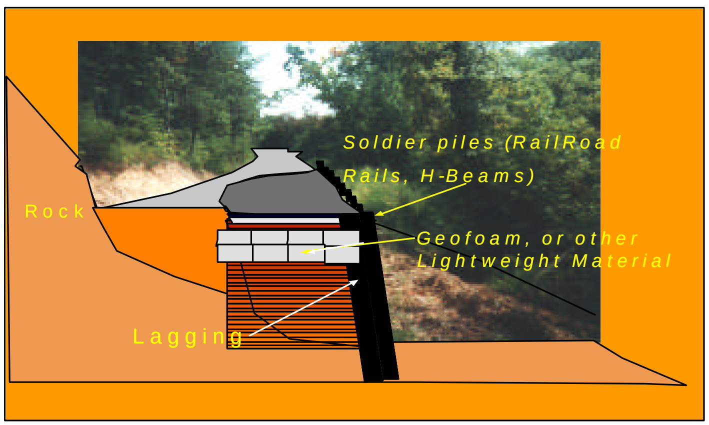


Figure 63. Repairing small highway landslides (20 ft or less) using railroad steel rails (anchored into bedrock) to form a retaining structure and lightweight backfill.

Figure 64. Installation in 1998 of railroad rails to form a wall to restrain a side hill landslide. Concrete panels were installed behind the anchored rails. The wall was backfilled with lightweight material, which consisted of cinders and shredded rubber tires.

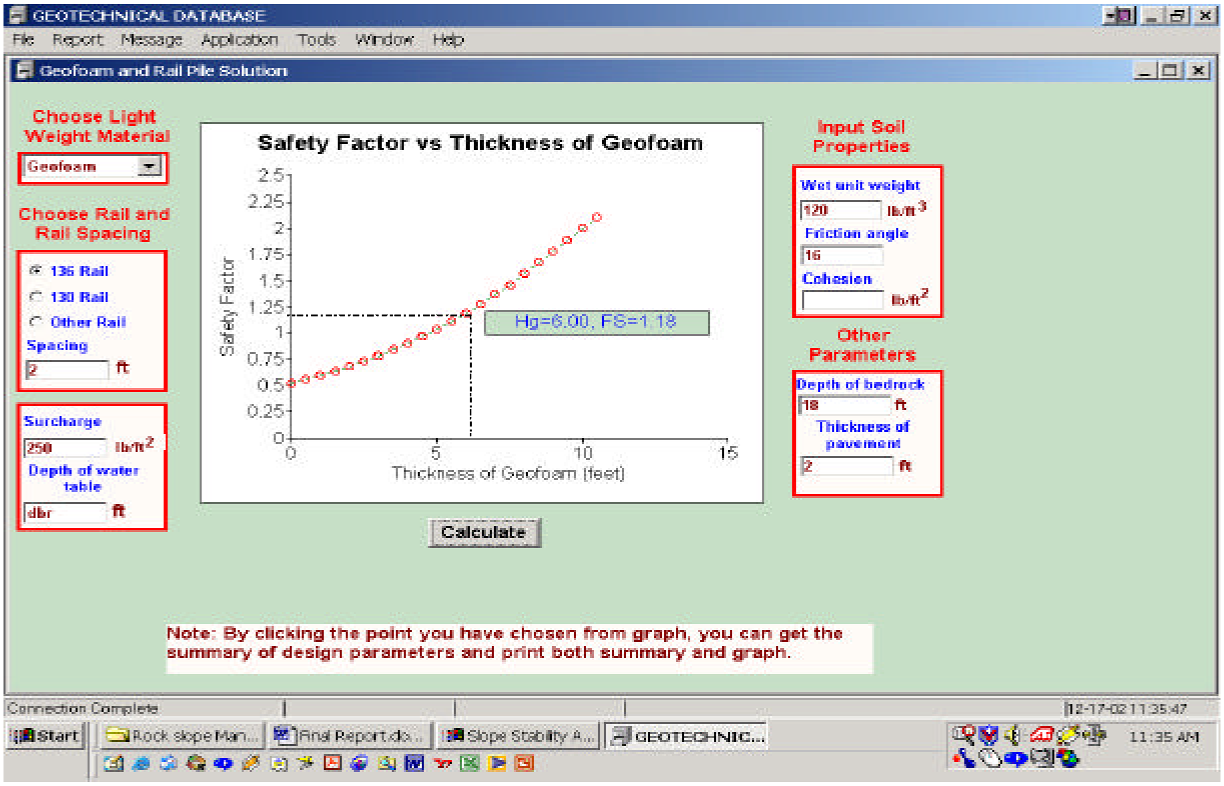


Figure 65. GUI data entry screen for designing a railroad rail retaining structure backfilled with lightweight material and regular fill material.

The database programs can be geared in the future to produce several types of designs in the geotechnical field. This will greatly increase the design efficiency, reduce errors, and supply uniformity. Furthermore, geotechnical staff of the central office can immediately review designs by district personnel and review comments can be transmitted through an internal message exchange channel setup inside the geotechnical database. This is particularly useful when remedial measures may be needed to handle some emergency cases, such as a highway landslide. The situation in the field can be sent to the database by digital photographs and cross sections. The state geotechnical and geologist staff can examine and evaluate the situation immediately. Properties of soil and rock in the field can be obtained from the database and used, when available, in the built-in applications to forge a " real-time" decision on the best approach to solving the emergency situation.

Other computer programs for performing routine analysis and design are continually being added to the applications' section of the database. For example, a windows-based computer program for analyzing reinforced and unreinforced earth structures (Slepak and Hopkins, 1993, 1995a, and 1995b), such as highway slopes and walls has been included. Graphical user interface screens for performing these types of analyses are shown in Figure 66 and 67. Data in Figure 67 shows the stability analyses of a slope using a noncircular shear surface.

This software can also be used to perform bearing capacity analysis, or stability analysis, of unreinforced flexible asphalt pavements, or flexible pavements reinforced with geotextiles (Hopkins, 1986; Hopkins, 1991; Hopkins, et al. 2002; Hopkins 1994a, b; Slepak et al. 1995b; Hopkins et al. 2002). Examples of graphical user interfaces for entering data and performing this

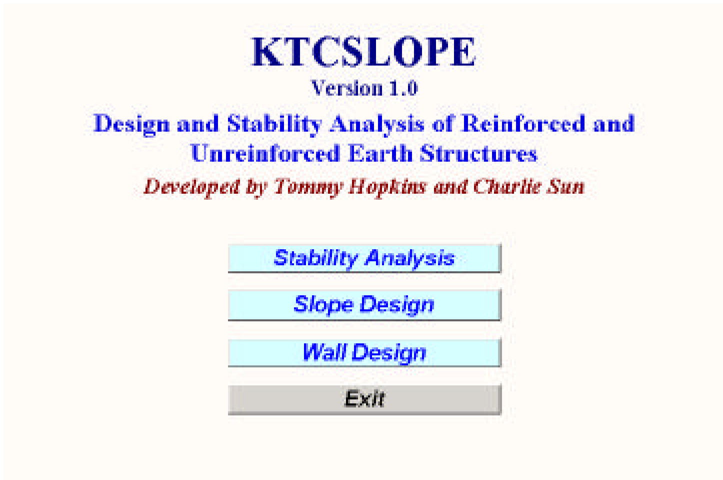


Figure 66. GUI screen (Main Menu) for analyzing the stability of unreinforced and reinforced slopes, walls, and flexible asphalt pavements.

type of analysis is illustrated in Figures 68 and 69. In Figure 68, the bearing capacity of an unreinforced flexible pavement resting on a soft soil subgrade is shown. The factor of safety against failure was about 1.00. Using geotextile reinforcement, the factor of safety (Figure 69) increases to about 1.30.

Software to be included in the database (under development) includes a windows-based computer program for analyzing and simulating rock fall at a selected rock slope site. Other engineering and management software will be added in the future.

Visual Features –Electronic Photographs and Map displays

This visual function is an extremely important feature for users. Colored photographs of highway sites, such as, landslide and rock slopes, can provide valuable visual information. Features can be viewed in photographs that are not necessarily evident in narrative descriptions, or if they could be described, the descriptions would have to be lengthy. Technically, handling visual data in a database is much more difficult than handling text data because visual data is much greater in size than text data. Because of the size issue, data transmitting speed, processing time, and storage space requirements are primary factors that must be considered. In the early development of the database, photographs were stored as a Bitmap file. The file size was 2.5 Megabytes (Mb). By saving the electronic file photographs in a JPEG format, the file size was reduced to 44 Kilobytes (Kb) and reduced space requirements. Currently, there are about 5,200 photographs (of landslide and rock slope sites) in the Kentucky Geotechnical Database. An example of a series of photographs of an example landslide was shown previously in Figure 31. By double clicking the computer mouse, an enlarged view of one of the small photographs stored in the database

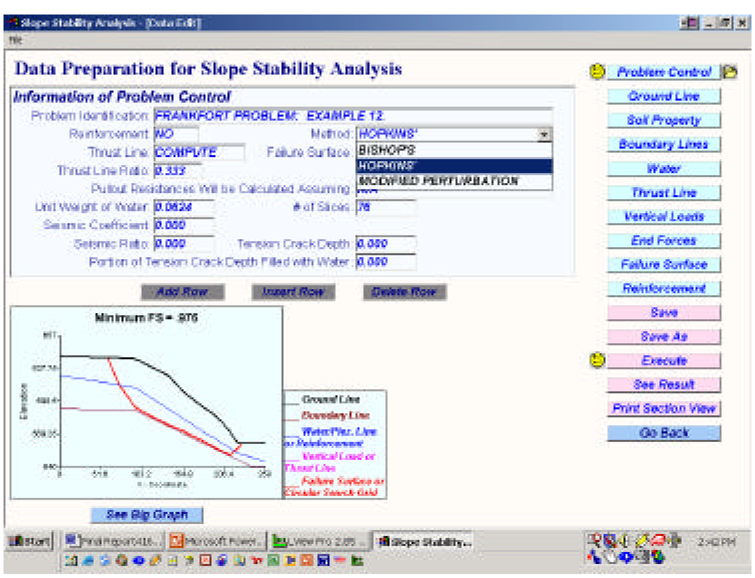


Figure 67. Graphical user interface for analyzing unreinforced and reinforced earth slopes and walls

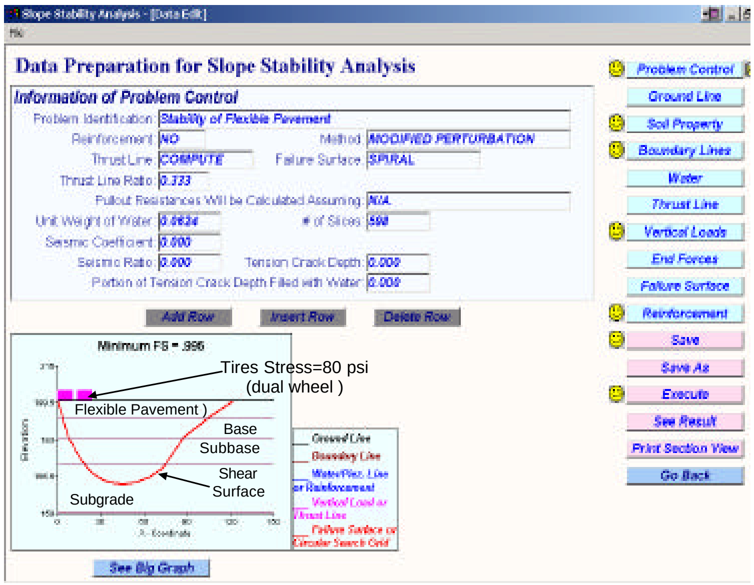


Figure 68. Data entry GUI screen for performing bearing capacity analysis involving flexible pavement multiple layers (unreinforced).

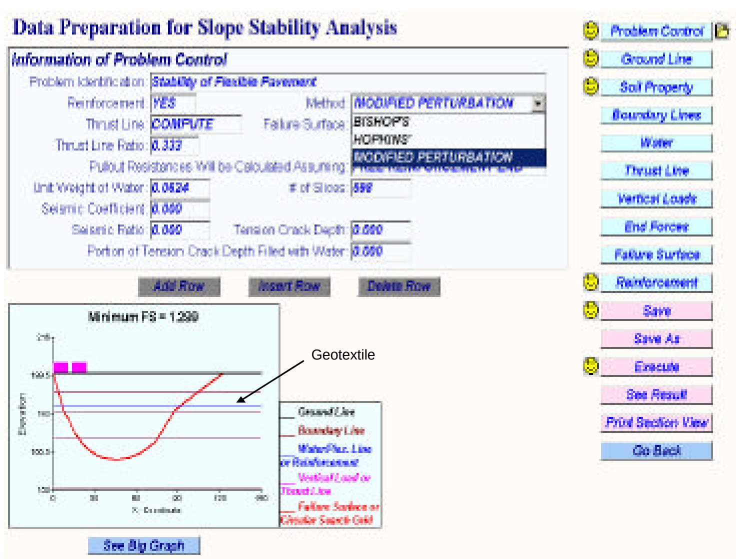


Figure 69. Data entry GUI screen for performing bearing capacity analysis of flexible pavement reinforced with geotextiles.

is obtained, as shown previously in Figure 32.

Other visual images embedded in the database include 120 county maps showing major highway routes of Kentucky. By using MapObject® software, processing speed for displaying maps is extremely fast, and maps can be displayed almost instantly. Moreover, locations and distributions of hazardous rock slope and landslides can be displayed on roadways of the embedded maps, since latitude and longitude of each site was obtained using GPS equipment. A zoom feature is included for enlarging viewing areas for details. An example of those features was shown previously in Figure 56. When a landslide location on the map is clicked, the user is switched to detailed information, and visa versa. A limited number of digitized geological quadrangles have been embedded in the database (the Kentucky Geological Survey has a program to digitize all geological quadrangles of Kentucky). Locations of holes can be displayed on the embedded roadway maps almost instantly. The user can click on a boring location and a plot of the boring, showing soil classification (as function of depth or elevation), is graphical displayed, as illustrated in Figure 56. Merely pointing and clicking the mouse can identify any roadway on the roadway map.

Security

In developing a database involving many users, database security is a major issue that must be addressed because stored data can be erased, or corrupted, unknowingly by users who are not familiar with the database protocol. To maximize the security of the Kentucky Geotechnical Database, three types of systems are used. The first is called the *registered user system*. The user must be approved by the Database Administrator and registered in the database. When the user logs on, Figure 70, the system automatically checks the user's identification and password. Only after the user identification and password matches the stored values is the user allowed the privilege of logging on and connecting to the database. The second security system is called a *role-based system*. Users are divided and assigned to different groups based upon their roles in the Geotechncial Database group. Hence, a hierarchy of users is established. Titles of users in the group include Database Administrator (DBA), Officer, Data Entry, Regional Data Entry, and Viewer. The DBA has full operational functions including read, insert, update, and delete. The Officer has a full operational function but cannot delete. Data Entry Users have full (add and delete) operational functions statewide. Regional Data Entry Users have full operational functions only for sites within their own district.

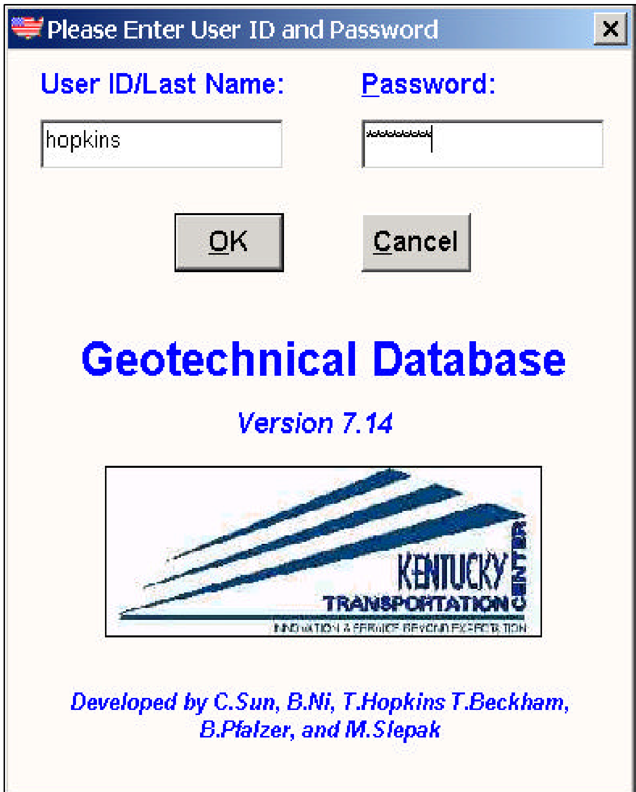


Figure 70. GUI security screen for entering user's ID and password.

The Viewer is only allowed to read and print stored data. Finally, the third security system is a recording system. Internally, the database application records and writes each operation performed by the user, such as logon and logoff times, insert, update, and delete operations. Reviewing this record, the DBA can not only trace the user's operations on the data, but also determine who is interested in the database. This feature is very valuable in tracking and locating errors in data entry, and for implementation of the database.

Engineering Units

Selection of the units for displaying engineering data is a major issue in developing an engineering database. Different users have different backgrounds and schooling, and they may find it difficult to use an unfamiliar unit system. The unit issue is also most important when different types of analyses are performed. If data were stored in the database in a mixture of both metric and English units, the user would have trouble in analyzing the data. For these reasons, all engineering data are stored in one system of units. In this case, the data is stored in Metric units. However, in the local interface, the user can switch to English and Metric units as desired. This feature applies to both data entry and data retrieval.

Strategies for Data Entry, Retrieval, and Map/Graphical Displays

Data Entry

To facilitate data entry, a series of graphical user interfaces were developed, as shown previously in Figures 27, 53, and 55. Tabs on the GUI data entry screen for landslides (Figure 27) include site information, attributes and impact, history (and severity rating), maintenance costs (and activities), and design and costs. When any one of these tabs is clicked, a GUI screen appears. For example, the GUI screen for attributes includes boxes for entering such information as contributing factors, utilities damaged and not damaged, average annual daily traffic and adjacent properties. Whenever possible, the "drop-down" list feature is used so the amount of typing is minimized. As noted previously, the main GUI screens contain a series of tabs near the top of the screen. For rock slopes (Figure 53), the tabs are labeled site information, total score, traffic, geometry, geologic character, climate/rock fall history, mitigation cost, report, and picture. The GUI screen for a rock slope site contains boxes for entering such information as route number, project type, milepost markers, latitude and longitude and other site information. Values--state plane coordinates--in NAD 27 and NAD 84 are automatically calculated from stored algorithms as well as latitude and longitude. By clicking a selected tab, a data-entry GUI screen, or report, or picture(s) appears.

The location/hole/sample GUI screen (Figure 55) contains tabs that are labeled site information, work phase, location/hole, sample, (engineering) properties, and (statistical) analyzer. When any one of those tabs is clicked, a data entry GUI screen appears. Work performed at different times at the same site is identified by work phases. Some types of information include hole number, sample type and number, elevations, work phase number, hole depth, depth to bedrock, water depth in hole, surface elevations, location accuracy of latitude and longitude, station number and offset, and USGS quadrangle number where the hole is located. When the engineering properties tab is clicked, a GUI screen is obtained, which displays a menu of soil properties, such as classification, grain size, CBR, laboratory strengths (different types of tests), field strengths (different types of tests), moisture-density tests, consolidation, visual manual descriptions, and resilient modulus test values. When an item on the menu is clicked, a GUI screen is obtained for entering the engineering data for the selected test. GUI screens for rock samples, locations, and properties can also be accessed. These screens contain such data entry boxes for hole number, type of boring, depth of bedrock, depth to the RDZ, station number and offset, sample type and number, elevations, and sampling method.

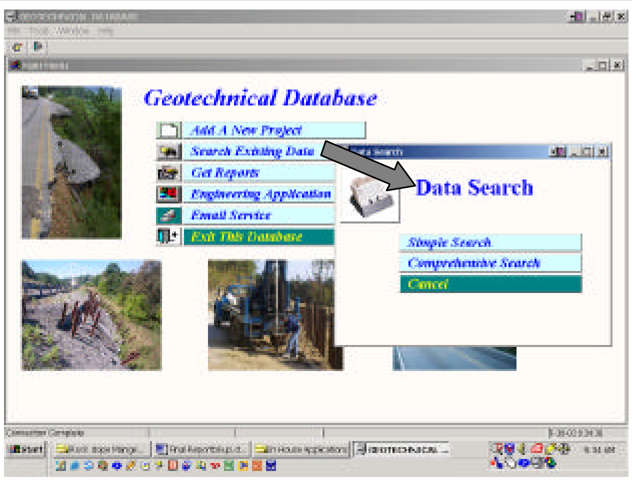


Figure 71. Types of data searches.

Data Retrieval Search Schemes

Different types of data retrieval schemes have been incorporated into the database, as shown in the main menu, Figure 71. In one approach, data can be retrieved using either a "Simple Search" or a "Comprehensive Search." When the simple search is executed, the GUI screen in Figure 72 appears. Different types of sites, such as landslides, or rock slopes, and their attributes may be retrieved for sites located in a selected county or geologic quadrangle, as shown in Figure 73.

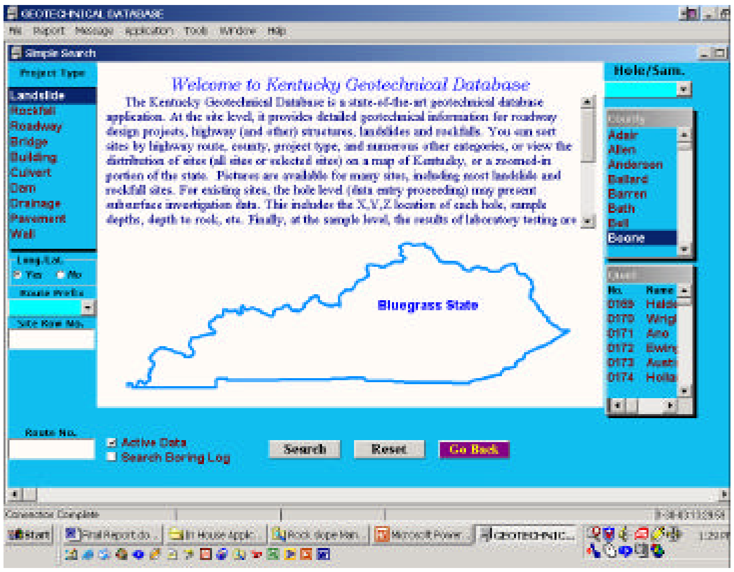


Figure 72. GUI screen for performing a simple data search.

The second retrieval scheme is a comprehensive search routine for amassing data. After clicking "Search Data" on the main menu (Figure 71) and "Comprehensive Search", the GUI screen shown in Figure 74 appears. This system uses a system of operators such as equal to, or greater than, less than, etc. Using this retrieval method, the user may construct any type of report. In this scheme, the user may use a simple "comprehensive" (upper button on the GUI) search routine involving a limited number of prefixed parameters and operators or the user may use a comprehensive scheme (lower button) using any number of

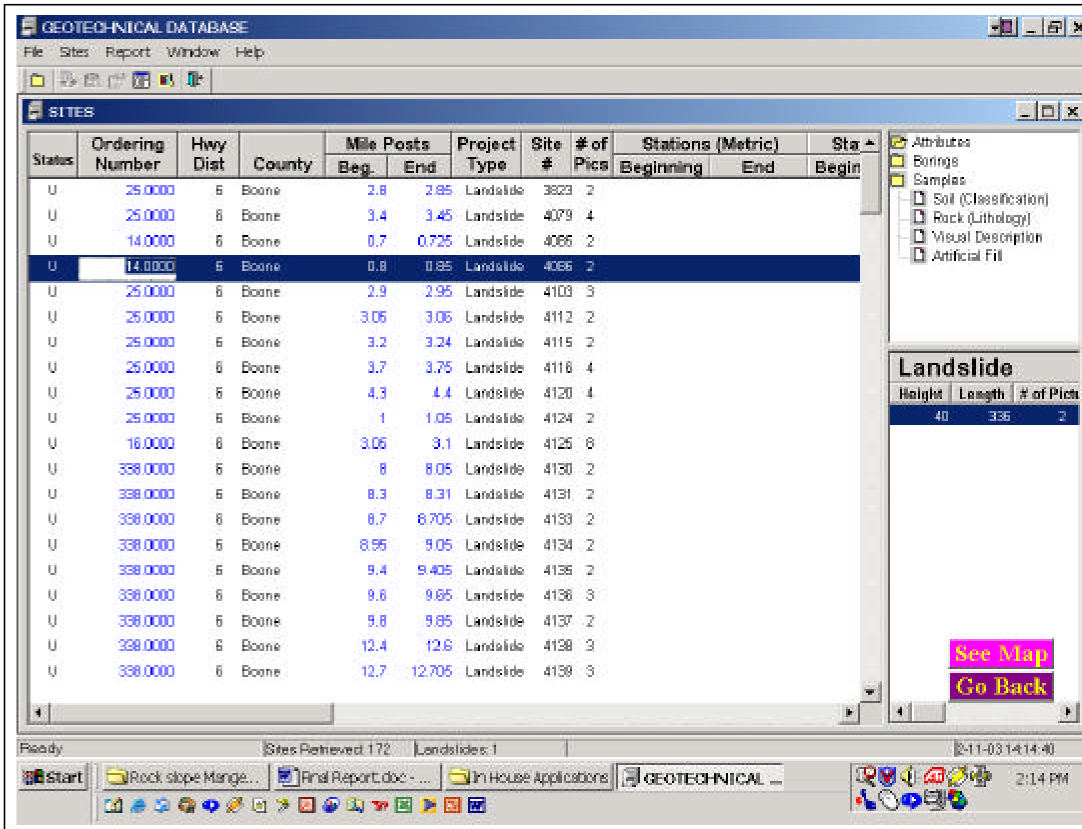


Figure 73. Data retrieved from the "Simple Search" routine.

selected parameters.

For instance, in the example shown in Figure 75, the user wanted a listing of all landslides on the Mountain Parkway in Kentucky that were located at or greater than mile point 33.6 and that have occurred before April 10, 2003. After clicking on the "Search Existing Data" and "Comprehensive Search," in the upper portion of Figure 75, and clicking the button, "Simple Search (on the Comprehensive Screen)" the screen in the lower portion of the figure appears. Using a dropdown list of routes, the user clicks "MT", uses the operator, > =, inserts 33.6 into the "Beg.MP" box, and uses the operator, < or =, and inserts the date, 04/10,2003. Clicking "OK," the data illustrated in Figure 76 appears.

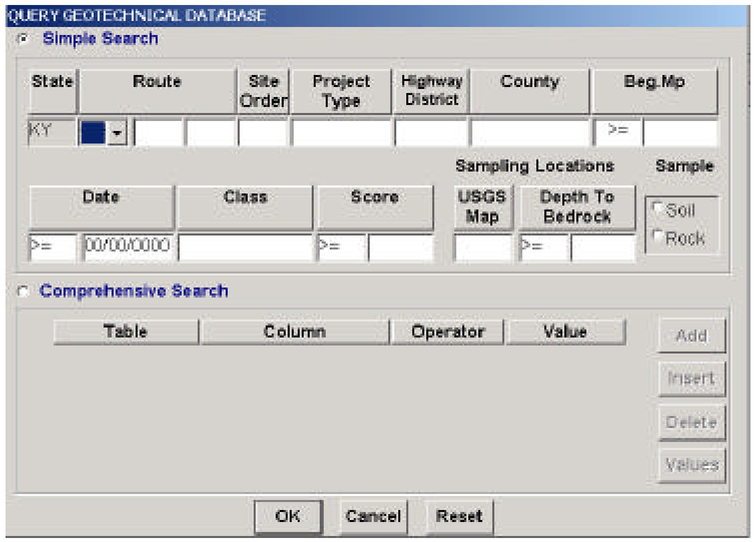


Figure 74. Comprehensive search GUI screen.

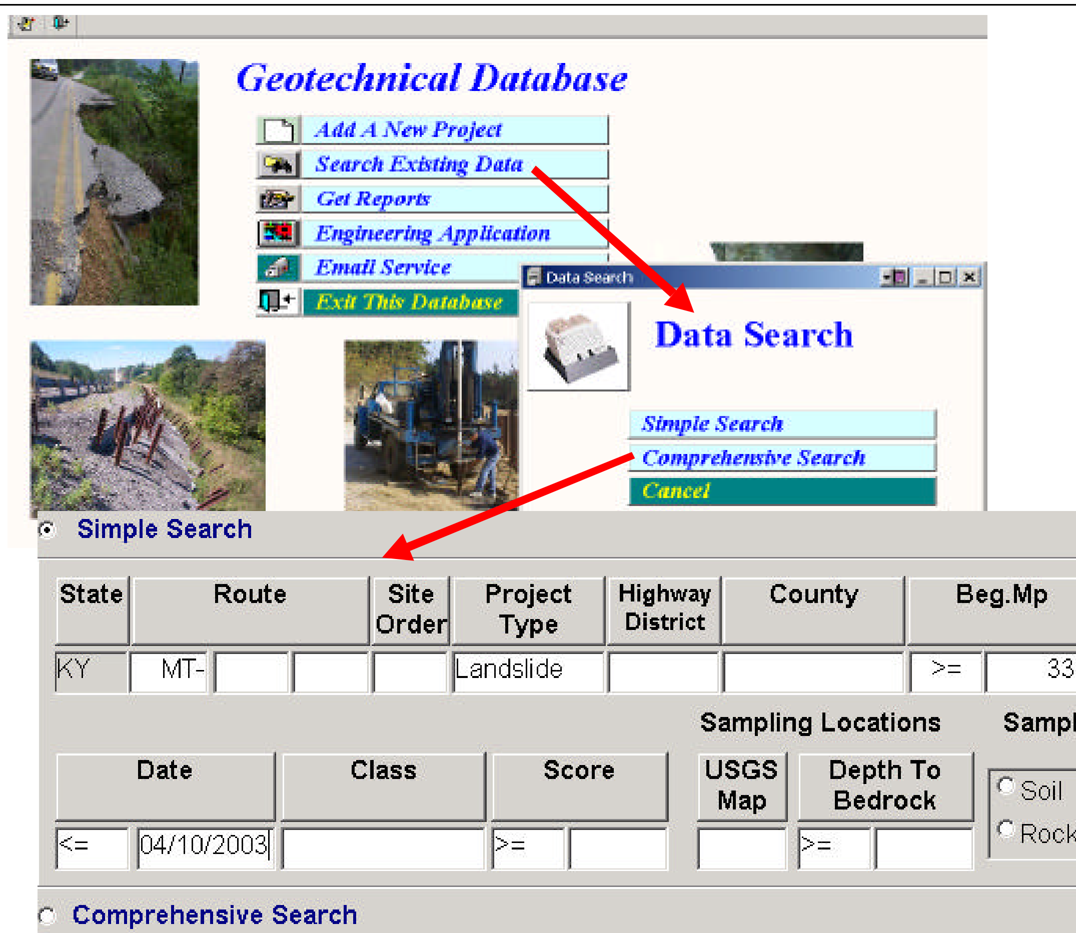


Figure 75. Method for performing a ("simple") comprehensive data search.

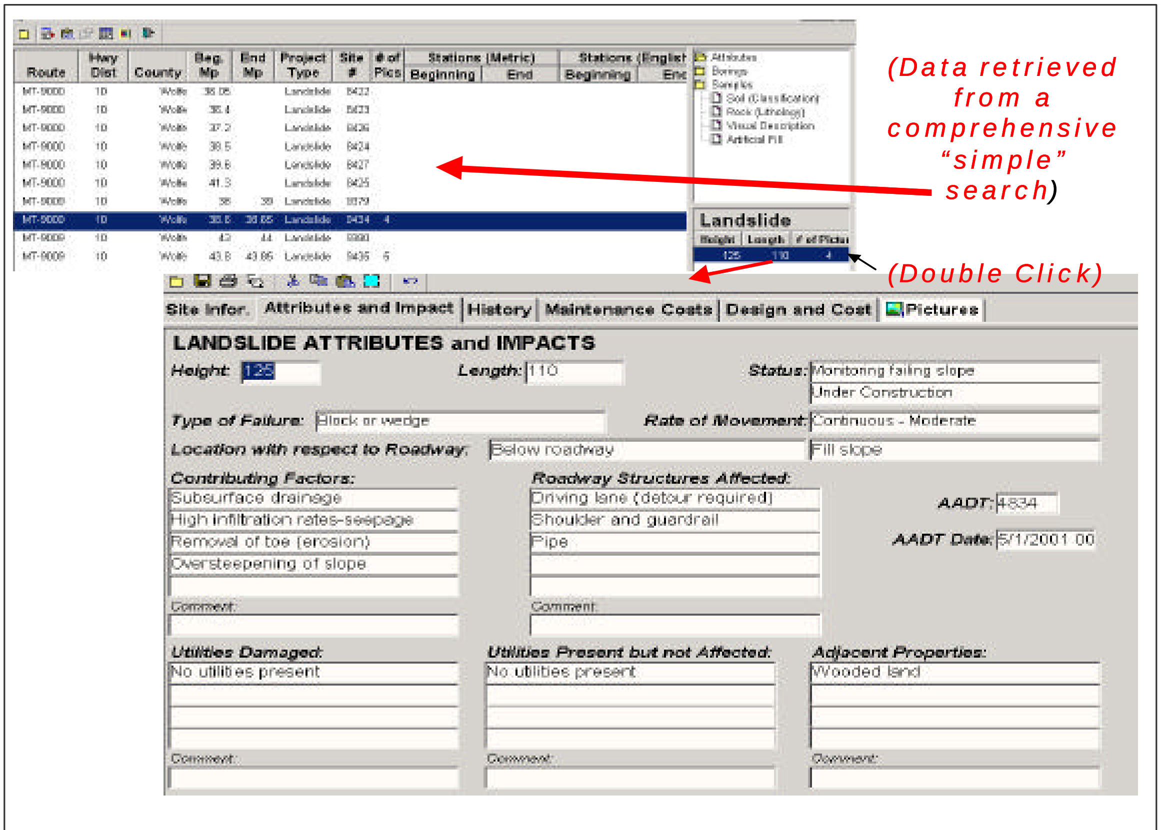


Figure 76. Retrieved data using the comprehensive "simple" search routine.

By double clicking on a selected landslide site, (highlighted at the right), the GUI screen at the lower portion of the Figure 76 appears. This screen displays a number of tabs, labeled "Site, Attributes and Input, History, Maintenance Cost, Design and Cost, and Pictures". Clicking any one of those tabs will display detailed information.

The comprehensive data search is illustrated in Figure 77. In the latter approach, the user may add as many database parameters and operators as desired to build the data search. In the example, the user is retrieving rock slopes that were rated (RHRS score) 650 but less than 670. In this case, two operators, > or = and <, were used to retrieve the desired data.

Data Report Schemes

In addition to the simple and comprehensive search features, another scheme has been included in the database for retrieving and generating data reports. When the "Get Reports" button on the main menu is clicked, the GUI screen shown in the right-hand portion of Figure 78 appears. Presently, the user has three choices for generating reports. These are titled "Special," " Flexible," and "Sample Properties". Other reports shown on the menu are under construction.

When the "Special" report button is clicked, the GUI screen in Figure 79 appears. Clicking on the "selection" button displays several choices: Counties, Route number, Highway District, Report Type (refers to reports issued by the Geotechnical Branch, Division of Materials, of the Kentucky Transportation Cabinet). This scheme allows the user to construct many different types of listings and combinations of various parameters. For instance, if the "Report Type" is clicked, then the listing, " B, L, M, R, and S," appears in the right-hand side of the GUI screen

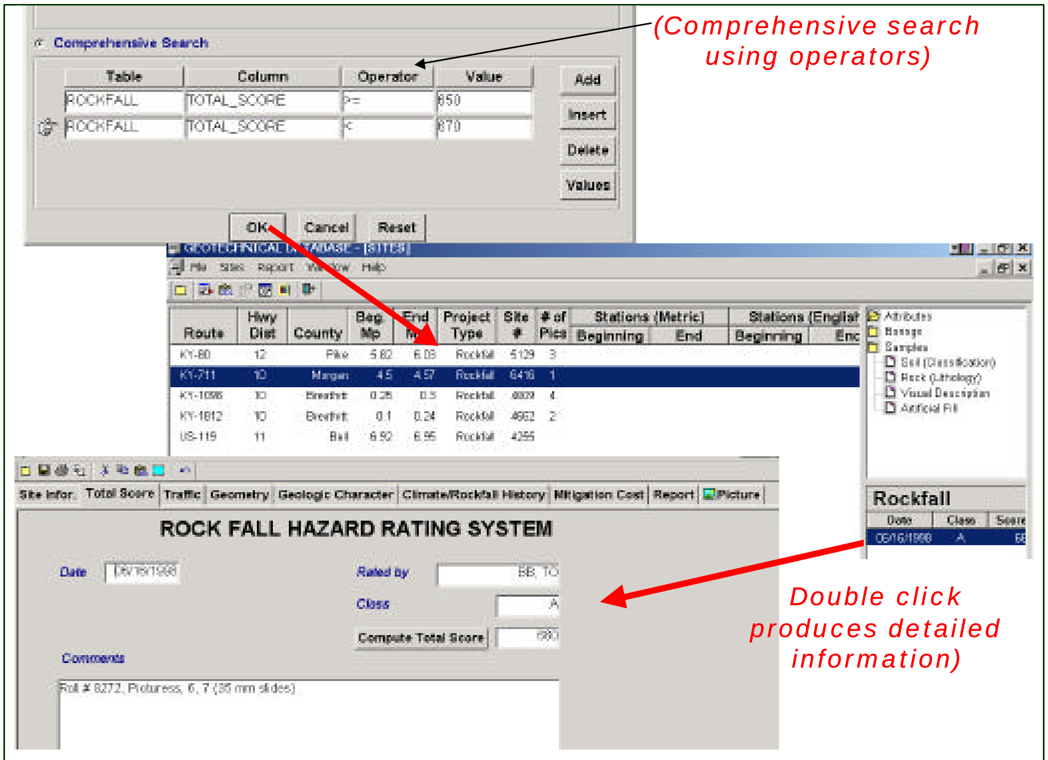


Figure 77. Comprehensive search using operators.

(Figure 78). Clicking, for example on "R" (rock fall reports), produces the listing of reports in the central portion of the GUI screen.

In the second type of report generator, data can be filtered to obtain the desired data. Although the parameters used for filtering are preset, as shown in Figure 80, a great deal of flexibility has been programmed into the filtering process. The database contains three preset filtering retrieval schemes. Soil and rock data and other attributes pertaining to landslides, roadways, rock slopes, SCS (Soil Conservation Service), and structures may be retrieved to generate reports. When the landslide button is clicked, the GUI format shown in Figure 80 appears. In this format the user may select a particular highway district[2], or a combination of

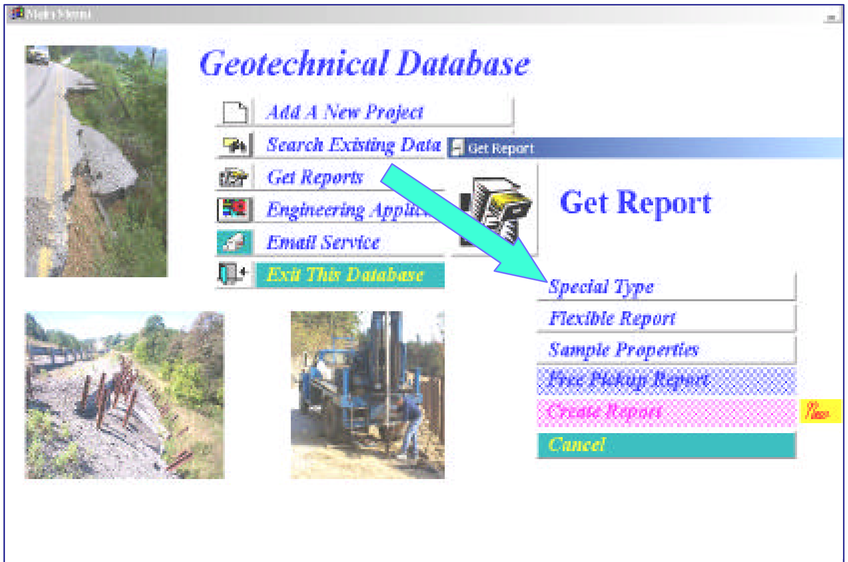


Figure 78. GUI screen for retrieving and generating reports.

2 There are twelve highway districts in Kentucky under the jurisdiction of the Kentucky Transportation Cabinet.

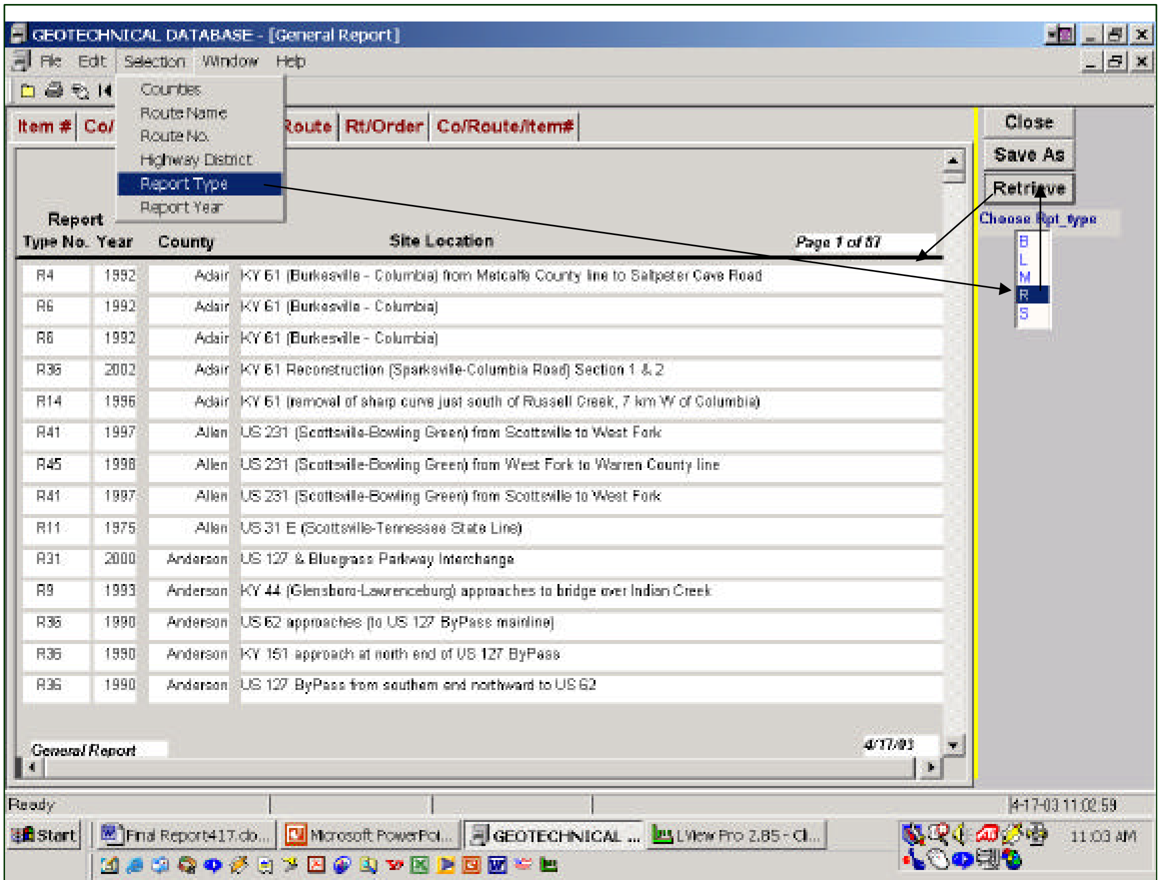


Figure 79. GUI screen for generating report listing.

highway districts, or "All" highway districts, route, the severity class of landslide (A, B, C, D)[3], landslide data collected by the Kentucky Transportation Cabinet (KYTC), or the University of Kentucky Transportation Center (UKTC), active or corrected landslides, boring log, latitude and longitude.

An example of using the flexible report procedure for compiling a landslide report is shown in Figure 80. In this example, the user is interested in obtaining a listing of active landslides that were rated "A" (very serious) in Highway District 6 in the northern portion of Kentucky. The user clicks "Landslide", "HW District" 6, Class "A" and punches the buttons "UKTC Data", "Active", and "With Long/Lat". When Highway District 6 is clicked, the counties in that district automatically are listed. The report is given a title as shown in Figure 80. After punching the "Retrieve" button, the GUI listing appears, as shown in Figure 81. The data shows that there are a total of 16 landslides in Highway District 6 rated "A". As of the date of this report, about 370 landslides have been identified in Highway District 6 that are rated "A" and "B"(very serious and serious, respectively). A total of about 545 landslides were identified in the district. A map of the "A" landslides may be obtained by clicking on "Distribution on Map". By highlighting and clicking on a site, the GUI shown in Figure 82 appears giving detailed information. Photographs of the site may be viewed by clicking "Pictures."

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[3] Severity classes of landslides were defined in a previous section entitled "Description of Landslide Database and Management Program," page 18.

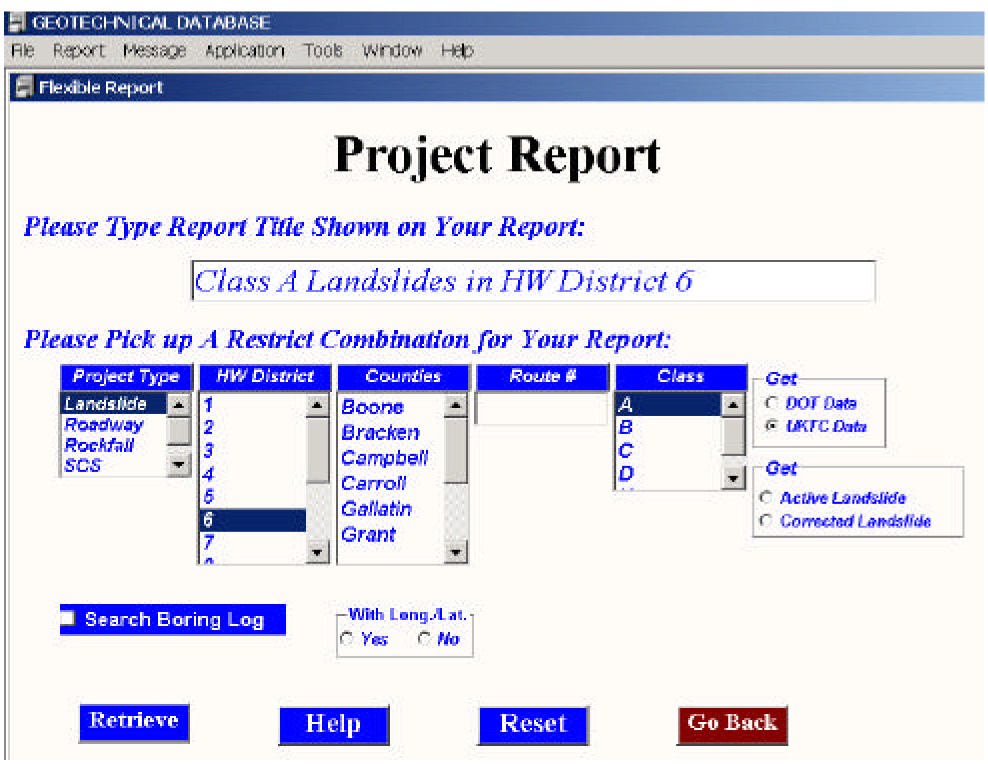

Figure 80. GUI format for filtering and generating a landslide report for a specific area (highway district or county), route(s), and class of landslide.

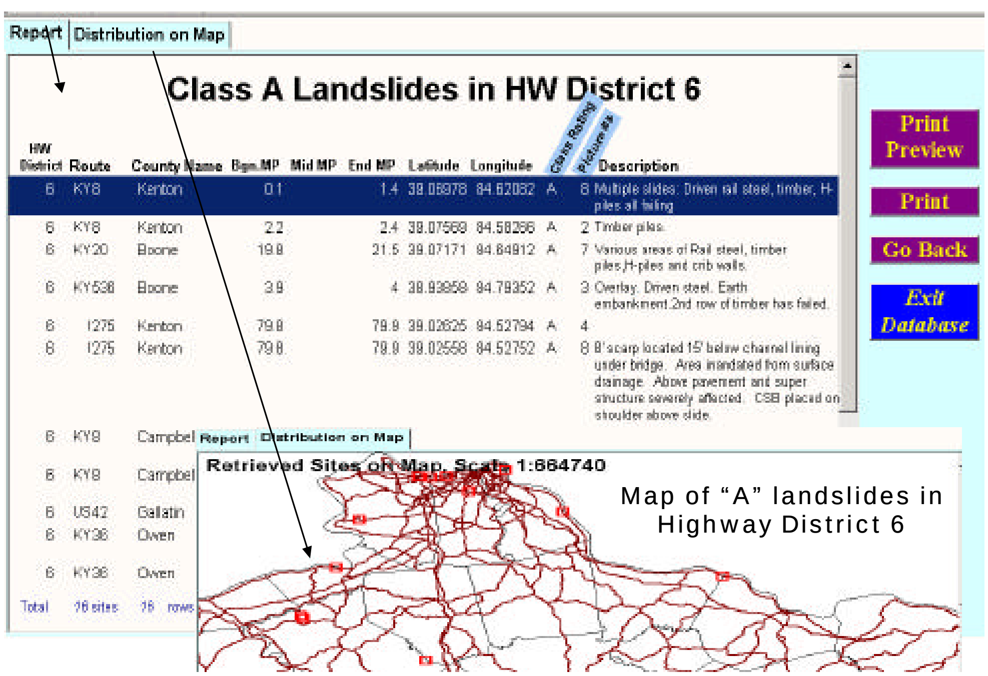

Figure 81. Report listing class "A" landslides in highway district 6 in northern Kentucky

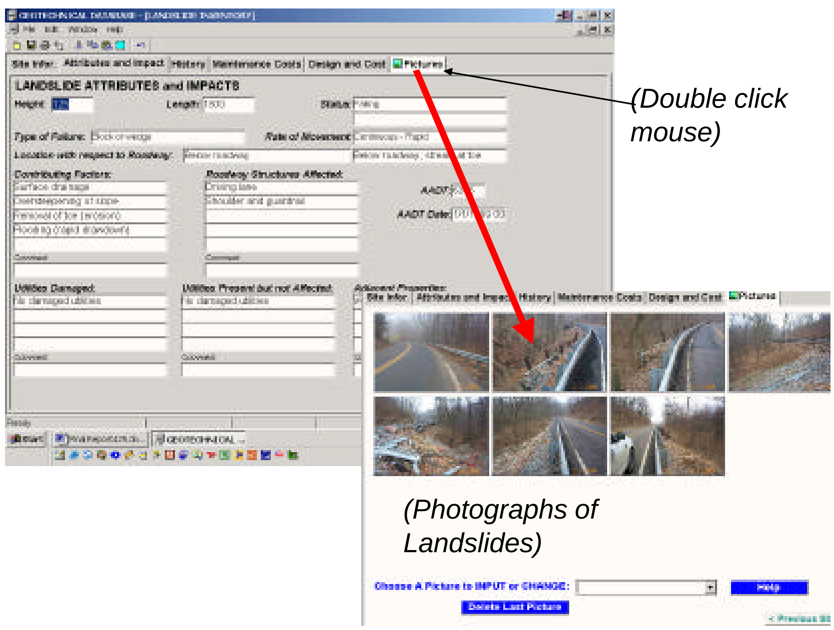

Figure 82. Details, including photographs, of a selected landslide

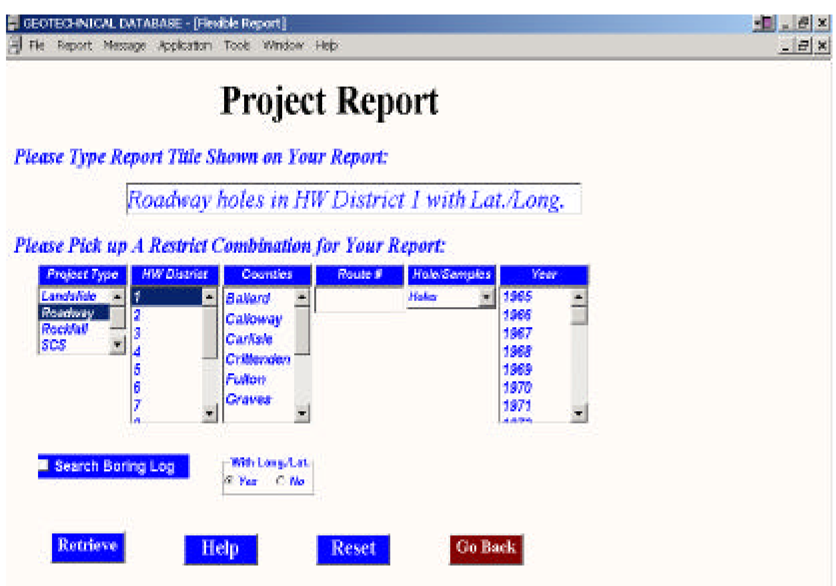

Figure 83. Compiling a listing of roadway holes in district 1.

As shown in Figure 83, the user may retrieve hole data. In this example, the user wishes to retrieve hole data that have been defined by latitudes and longitudes in Highway District 1. The user clicks "Roadway," "HW District" 1, "Holes," and "With "Long. /Lat." The listing appears as shown in Figure 84. By clicking on "Distribution on Map", view of the holes on a map of the western portion of Kentucky appears. The user may use a zoom feature to get closer views of the plotted holes.

Another example of using the filtering process is illustrated in Figure 85. In this example, potentially hazardous rock fall sites on interstate 75 in Kentucky having a numerical rating (ODOT Rockfall Hazardous Rating System) equal to or greater than 350 is sought. The report that is generated is illustrated in Figure 86. By clicking on any heading, the data are sorted (ascending or descending) according to the selected heading. For instance, by clicking on the heading, total "score" the user can arrange the data in ascending numerical scores. Moving the cursor to any selected site (highlighted) and double clicking takes the user to detailed information of the rock fall site. By clicking on "see Map" the rock fall sites on Interstate 75, having numerical ratings of 350 or greater, are displayed on a roadway map of Kentucky (lower right-hand portion of the figure).

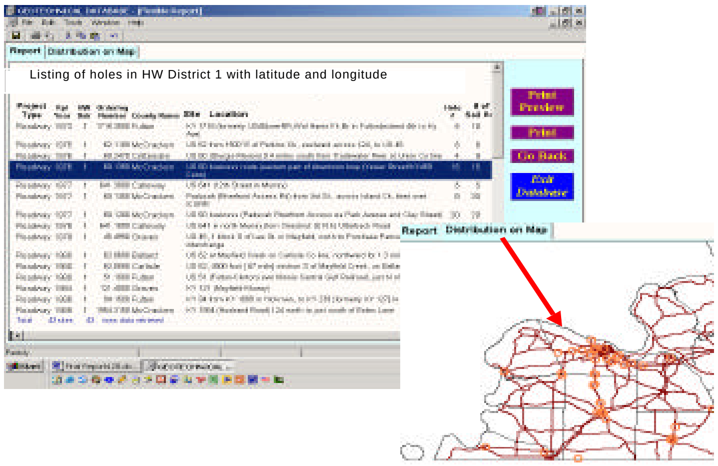

Figure 84. Listing of holes in Highway District 1 with latitudes and longitudes.

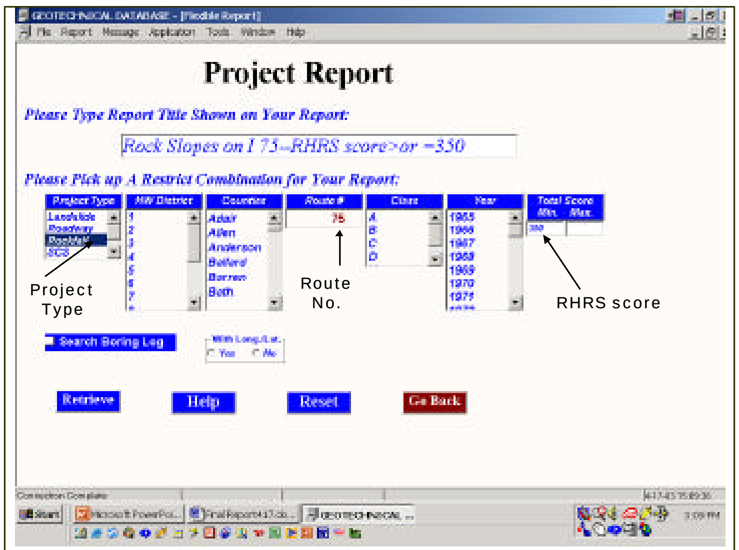

Figure 85. Compiling a listing of rock slopes on I 75 with RHRS scores greater than or equal 350.

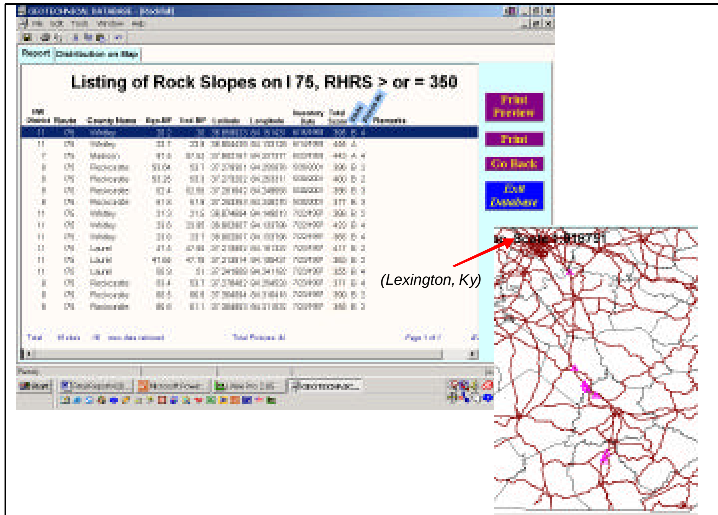

Figure 86. Listing of rock slopes on I 75 with RHRS scores greater than or equal to 350.

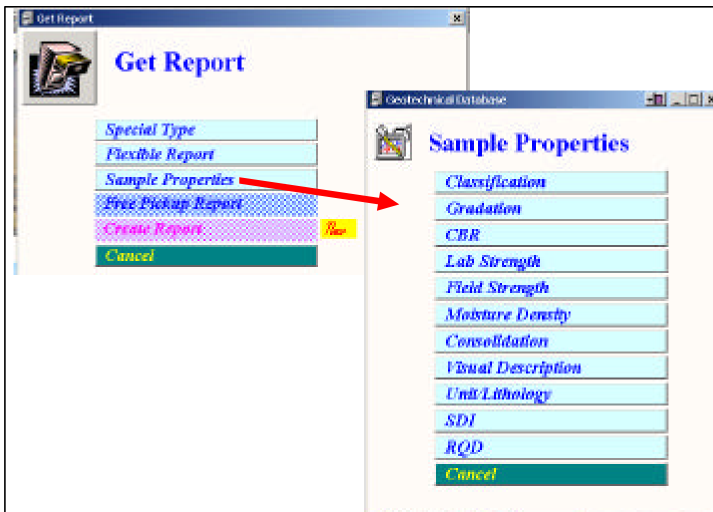

Figure 87. Method of retrieving soil properties of all stored data in the database

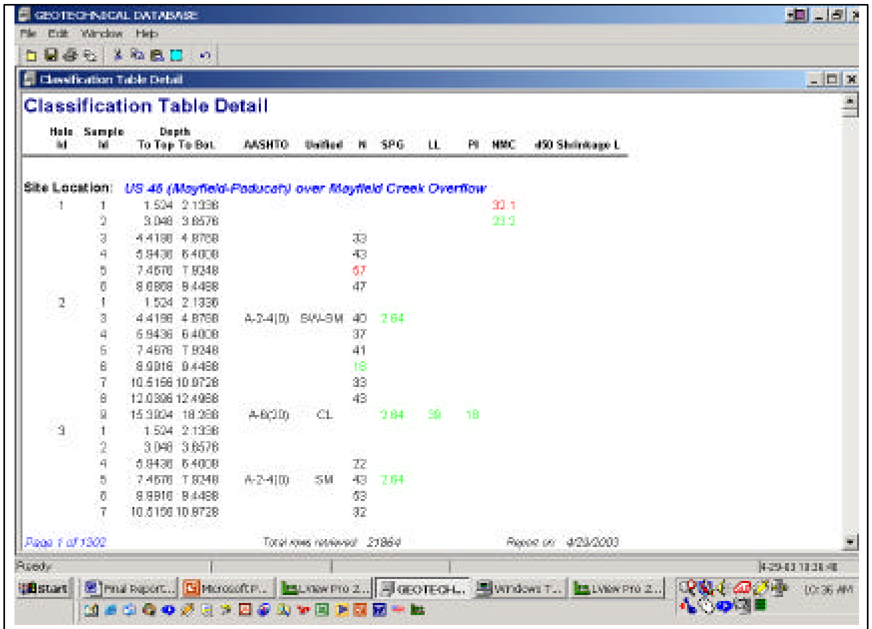

Figure 88. Listing of classification data.

As shown in Figure 87, soil and rock data properties in the database may be retrieved using the "Sample Properties" of the main menu. For example, if "Classification" on the menu is clicked, then classification data of all stored data is retrieved as shown in Figure 88. Tables of other sample properties, such as gradation, CBR, lab and field strengths, consolidation, visual descriptions, slake durability, and rock quality designation (RQD), may be obtained.

Internal Database E-Mail Mail

An internal E-mail scheme has been built into the Kentucky Geotechnical Database. This mechanism restricts the use of the e-mail to mainly business and prevents users from receiving "Spam," advertisements. The graphical user interface screen for sending and receiving messages from other users is shown in Figure 89. A list of users can be stored in the database e-mail as shown in the right-hand portion of Figure 89. To send a message to one of the users in the list, the name of the person the message is addressed is clicked. The name of the user sending the message is automatically logged into the "From" box and the person sending the message is automatically logged into the "To" box. A file may be attached to the message. After typing the message and attaching a file, the "Send" button is clicked to send the message.

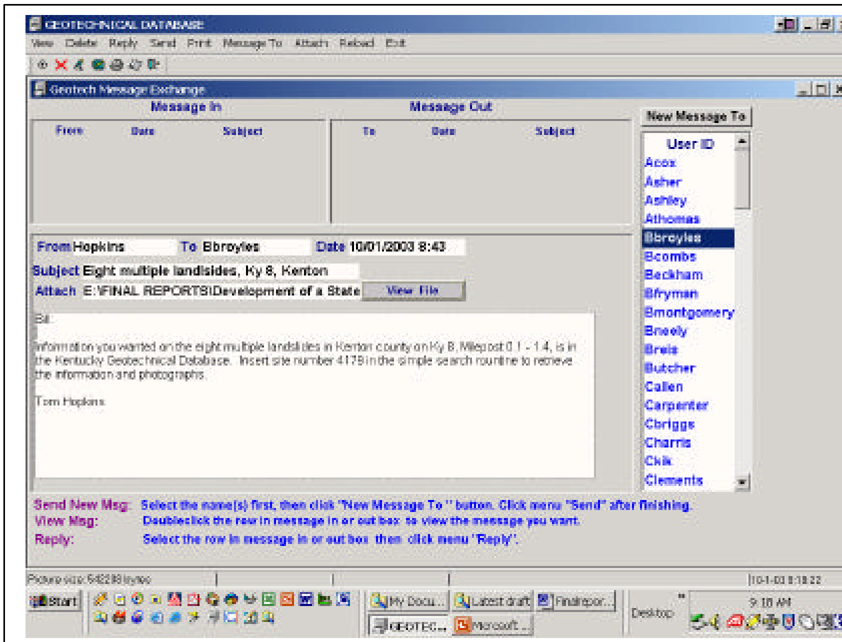

Figure 89. GUI screen for transmitting internal E-mail in the Kentucky Geotechnical Database.

SUMMARY AND CONCLUSIONS

As a means of establishing a comprehensive system for managing landslide problems in Kentucky, a geotechnical database was developed and is described herein. Developing a geotechnical database in a client /server and windows environment facilitates and provides an efficient means of entering and retrieving geotechnical data. Development tools included Oracle® 8i and PowerBuilder® 8.0 software. The database was partitioned into major and secondary components. Major parts of the database consist of rock slope, landslide, structures, roadway, and soil and rock engineering data. Programmed procedures of the database are used by the Kentucky Transportation Cabinet to identify hazardous conditions and for risk management of landslides. Procedures for entering and retrieving historical soil and rock engineering data have been developed. Procedures for retrieving soil and rock data, as it is generated, are under development. Methods of analyzing data statistically while connected to the database were developed for user convenience. Also, design applications, such as pavement design, or retaining wall design, have been developed and are included in the database as a convenience to users and to improve efficiency. Other applications are under development. Three procedures for safeguarding use of the database are described. Engineering units are stored using one system of units, but conversions from one system to another can be made on screen at any time. Saving and storing electronic photographs using JPEG software minimized storage requirements and, yet, did not sacrifice picture quality. File size of each photograph was only about 44 Kilobytes. MapObjects® software provided a good means for displaying quickly roadway maps and overlays of locations of landslide, rock slope, and boring locations. This report focused on building a system for managing landslide problems.

The actual numbers of potentially landslides existing on highways under the jurisdiction of the Kentucky Transportation Cabinet were unknown prior to this study. This report and the inventory of landslides performed on Kentucky's highways represents a response to a suggestion by FHWA. These efforts represent the first major step in attempting to correct landslides problems in Kentucky. To develop an effective management plan requires identifying and developing information of landslide (and rock fall) sites where future corrections and reconstruction may be needed to improve safety and to maintain, or, increase the traffic capacities of roadways. The main focus of this study and report was developing an inventory of highway landslides on Kentucky's highways and developing a landslide management database system. Inventory data is stored on a server of the Kentucky Transportation Cabinet. All twelve Highway District Offices and several Central Offices (in Frankfort) of the Kentucky Transportation Cabinet are connected to the database and server. Hence, the data is readily accessible.

Based on the inventory of highway landslides Kentucky, the following observations are offered:

- ?? About 1,400 landslides were identified on major highway routes under the jurisdiction of the Kentucky Transportation Cabinet. The location of each site was uniquely defined by using GPS equipment to obtain latitude and longitude (sub meter accuracy). Attributes and photographs of each site were cataloged and stored in the Kentucky Geotechnical database.
- ?? At the time of this study, about 57 percent of landslides, or the majority of the landslides surveyed, were assigned a severity category of category "C.' Landslides in this category

are characterize by moderate movements and breaks in pavements that occur over a period of several years. Pavements in this category will eventual need remedial attention. About 24 percent of the landslides were assigned to a severity category of "B." Landslides in this category generally require constant maintenance since they are usually moving rapidly. Approximately 5 percent of the landslides were assigned to a severity category of "A," or the most severe rating. Those landslides usually involved a lane closure, buildings may be in danger, or there is a safety concern and immediately attention is required. Only about 14 percent of the landslides were assigned to the category "D." Landslides in this category usually involve minor problems, or slope failures that affect the slope only.

?? Approximately 40 percent (545) of the surveyed landslides occur in Highway District 6 of the Kentucky Transportation Cabinet. This district is located in Northern Kentucky and contains large qualities of the Kope Geological Formation. The highly plastic clay shales of this unit have caused enormous stability problems. About 80 percent of the landslides in District 6 are concentrated in four counties—Boone, Grant, Kenton, and Owen. About 214 (16 %) landslides were located in Highway Districts 1, 2, 3, 4, and 5. Approximately 140 (11%) landslides occur in Highway Districts 7 and 8. In the mountainous areas of Highway Districts 9, 10, 11, and 12, about 450 landslides (33%) were identified.

?? About 50 percent of the landslides in the survey occurred in the Bluegrass Physiographic Region of Kentucky.

?? Estimated cost to repair the number of landslides in the survey may range as high as 400 million dollars. This is a very rough estimate of the costs. Federal assistance will be needed in the future to fund those repairs.

?? Steel rails were the most frequently repair method selected by Cabinet personnel. In this approach, rail steel is driven, or anchored into bedrock, to form a retraining structure. At about 180 sites of 282 sites where repairs were attempted, steel rails were used in attempts to halt landslide movements. However, this technique did not always work, especially when the height of landslide is greater than 20 feet. The success rate of this technique was not determined during this study and a more in depth study will be needed to determine the success rate and economics of this technique.

?? Heights of approximately 39 percent of the landslides in the survey were equal to or less than 20 feet. Heights of about 61 percent of the sites ranged from about 21 to 100 feet.

?? Lengths of about 200 landslides (15%) were less than or equal to 100 feet. The lengths of 80 percent of the landslides ranged from about 201 feet to values greater than 900 feet.

RECOMMENDATIONS

?? The Kentucky Transportation Cabinet should implement the landslide database and management system described herein. To make the system effective and to maximize benefits, it is important for Cabinet personnel to begin entering field data. For example, field personnel should enter historical events at a site such as patching of the roadway in the slide area, record movements of fences, guardrails, and other events such as the development of cracks in the pavements. Expenditures of remedial efforts should be noted at each site and the success of a repair effort.

?? The Kentucky Transportation Cabinet should seek federal participation and funding to repair the many landslides that exist on Kentucky's highways. This could take the form of a of program similar in scope to the "Bridge Replacement Program." Not only do the large number of landslides pose a safety risk to the traveling public, but also delays caused by landslides are a concern.

?? The role of steel rails in repairing landslide should be studied in detail. In particular, the success rate of this technique should be thoroughly investigated, as well as the economics of this repair technique. Although this technique may be useful in small landslides, it is very questionable, based on observations and theoretical calculations, that this method can be used effectively when the height of the landslides is greater than 20 feet. Although this technique may be economical for landslides less than 20 feet, it can lose it economical appeal if the success rate is much lower than 100 percent. Hence, a detailed examination of this repair technique should be considered. If the success rate is shown to be below 100 percent, than management guidelines need to be adopted (or restated) that prevent the use of this technique in situations where it is obvious that the technique will not work.

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