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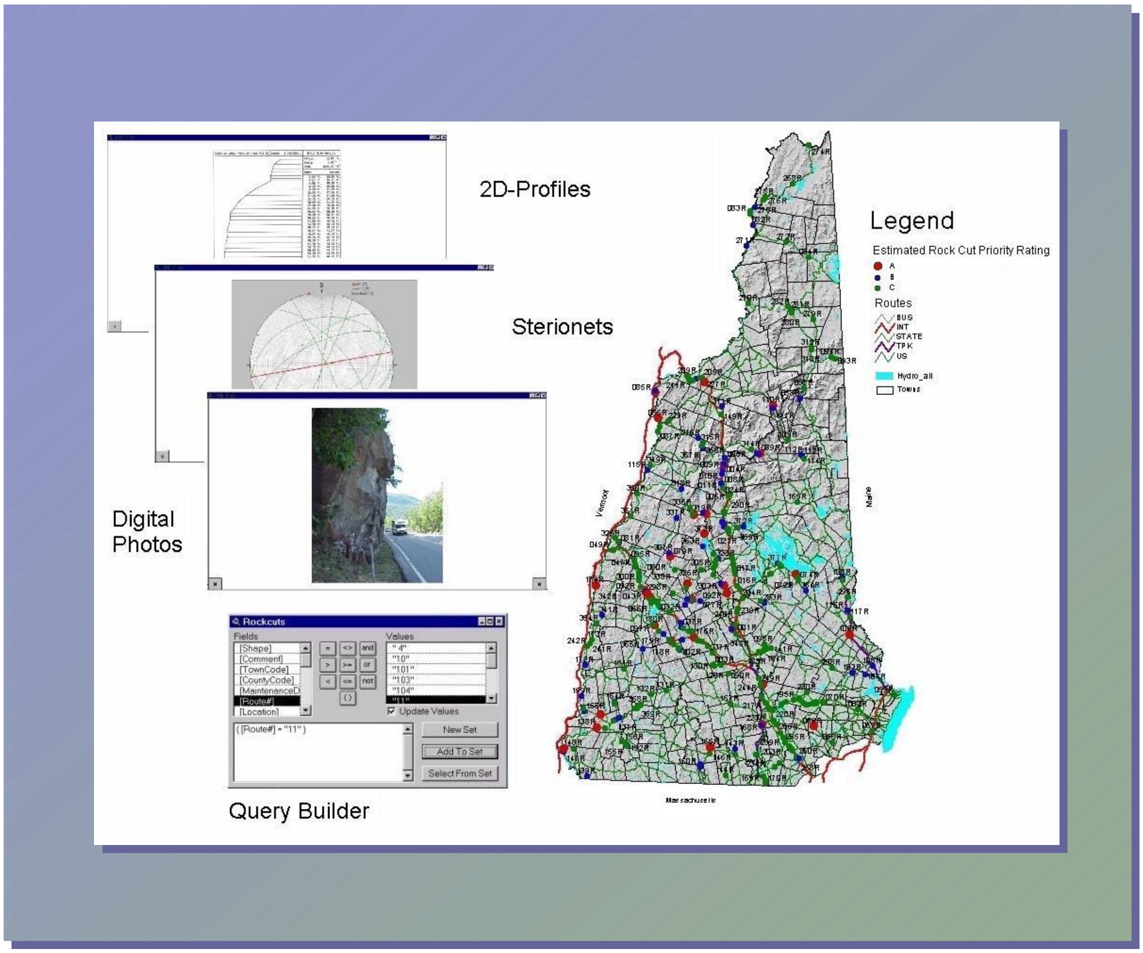

GIS and the New Hampshire Rock Cut Management System

Final Report

Prepared by the New Hampshire Department of Transportation, in cooperation with the U.S. Department of Transportation, Federal Highway Administration

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16. Abstract

The New Hampshire Department of Transportation (NHDOT) first conducted a Rock Cut Hazard Survey in 1975, which included 182 rock cuts. The program has evolved since 1975, and now incorporates 380 rock cuts and four different Rock Fall Hazard Rating Systems. By utilizing New Hampshire's State Planning and Research (SP&R) funding, a research project was initiated to investigate combining new rock cut data with pre-existing data into a Geographical Information System (GIS). Rock cut point features were collected for every rock cut with a Global Positioning System (GPS) and were added as a data layer on top of existing data coverage available through the Department's GIS server. A relational database was developed which would store all the rock cut data and be linked to the GIS through a structured query language (SQL) connect statement. A Brunton compass was used to collect rock cut structural data and a digital camera was used to photograph every rock cut. The structural data was graphically represented in the GIS in the form of rose diagrams, stereonets and density plots. A laser profiler was used to collect two-dimensional profiles on selected rock cuts so rock fall simulations could be conducted. The GIS does have limitations, which include: The network bandwidth, accessibility restrictions, and resource allocation for maintaining current and accurate data. Deployment of an Internet Mapping Service has been recommended to increase accessibility and to allow all NHDOT users access to the Rock Cut Management System through a web browser.

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EXECUTIVE SUMMARY

The New Hampshire Department of Transportation (NHDOT) first conducted a Rock Cut Hazard Survey in 1975, which included 182 rock cuts. The program has evolved since 1975, and now incorporates 380 rock cuts and four different Rock Fall Hazard Rating Systems. By utilizing New Hampshire's State Planning and Research (SP&R) funding, a research project was initiated to investigate combining new rock cut data with pre-existing data into a Geographical Information System (GIS). Rock cut point features were collected for every rock cut with a Global Positioning System (GPS) and were added as a data layer on top of existing data coverage available through the Department's GIS server. A relational database was developed which would store all the rock cut data and be linked to the GIS through a structured query language (SQL) connect statement. A Brunton compass was used to collect rock cut structural data and a digital camera was used to photograph every rock cut. The structural data was graphically represented in the GIS in the form of rose diagrams, stereonets and density plots. A laser profiler was used to collect two-dimensional profiles on selected rock cuts so rock fall simulations could be conducted. The GIS does have limitations, which include: The network bandwidth, accessibility restrictions, and resource allocation for maintaining current and accurate data. Deployment of an Internet Mapping Service has been recommended to increase accessibility and to allow all NHDOT users access to the Rock Cut Management System through a web browser.

INTRODUCTION

In August of 1975, the Engineering Geology Section of the New Hampshire Highway Department completed a survey of rock cuts along New Hampshire's state and federal highways (Baldwin, "unpublished data"). The purpose for the survey was to identify potentially unstable rock cuts, so remedial maintenance could be planned before failures occur. In addition, the survey attempted to correlate rock cut stability to such local factors as rock type, hydrology, construction methods and geology.

To keep the survey to a reasonable size and to insure all potentially hazardous rock cuts would be investigated, only cuts of twenty-five feet or higher were examined. It soon became apparent that some cuts smaller than twenty-five feet in height were also potentially hazardous. Therefore, a final judgment on the cut's inclusion into the survey had to be based on a combination of objective and subjective factors. Each cut was screened not only in terms of height, but also in terms of its lateral distance from the roadway, structural geology and its degree of decomposition due to weathering.

Initially, each rock cut was assigned a unique three-digit number as it was located in the field. The numbers are in no sequential significance because they were assigned in the order at which the rock cuts were encountered. A complete follow up investigation was conducted for each rock cut at a later date. Data collected during this follow up investigation included: Location, dimensions, rock types, hydrology, construction methods, climatic zones, remarks, prominent geologic structures with the orientation of each structure in terms of strike and dip, and current condition (a performance rating of "good", "fair" or "unsatisfactory" based upon a total evaluation of all the features of the cut). One hundred and eighty two rock cuts were included within this initial survey.

In 1983, the New Hampshire Department of Transportation (NHDOT) started to enhance their initial Rock Cut Survey by implementing a Slope Stability Program outlined in a FHWA Rock Slopes Manual (*1*). A stability assessment form, provided within the manual and slightly modified to fit NHDOT requirements, was used to evaluate existing rock cuts within the NHDOT Rock Cut Survey and to add new sites as they were located or constructed. The stability assessment in the FHWA manual assigned a priority rating ("A" through "F") to a rock cut based upon the probability of a slope failure and rock reaching the roadway. The NHDOT reduced these priority ratings to three categories ("A" through "C") where rock cuts with an "A" rating have the highest priority and rock cuts with a "C" rating have the lowest priority. In addition, photographs of all the rock cuts were taken to help identify the sites in the field and to document existing conditions.

In 1987, Duncan C. Wyllie of Golder Associates developed a rock slope inventory and maintenance program, which was presented at the FHWA Rock Fall Mitigation Seminar in Portland, Oregon (*2*). Shortly thereafter, the NHDOT started using this system to evaluate both their existing rock slopes and new ones as they were located or constructed. This system assigned actual scores to each rock cut based upon the rock cuts dimensions, site distance, traffic volumes, ditch dimensions, geology, block sizes, rock friction, climate and rock fall history. The rock cut's final score determined which of the three NHDOT priority categories it would fall within.

In 1989 the NHDOT, along with 9 other states and the FHWA, participated in a pool-funded study to develop a Rock Fall Hazard Rating System (*3*). The Oregon Department of Transportation was the performing organization for the study. By August of 1989, a fully tested and developed implementation manual was completed, which documented all the components of a RHRS. Upon the publication of this manual, the NHDOT started to re-evaluate all its rock cuts. By following the criteria within the RHRS manual, additional data was collected for each rock cut, which included sight visibility, ditch dimensions, traffic volumes, instability types, and the size of any occurring rock fall. Scores were assigned to each rock cut based upon all the collected information and cuts were grouped into 3 categories (A=high hazard, B=moderate hazard, and C=low hazard). Modifications were made to the RHRS in order to more closely resemble conditions in New Hampshire. These modifications included the assignment of points above or below the four given scores for each category and the inclusion of slopes with a lower slope height. By 1994, the NHDOT had completed a preliminary evaluation of all its rock cuts and ranked eighty-five cuts as "A" and "B" under the modified Wyllie's Hazard Rating System. An inspection program was developed where all "A" rock cuts were visited annually, all "B" rock cuts every 3 years and all "C" rock cuts every 5 years.

In May of 1993, the New York Department of Transportation (NYDOT) published a working draft of a Rock Slope Hazard Rating Manual (*4*). This manual outlined the creation of three "factors" (geologic, section and human exposure), which are used for computing the "total relative risk" of a rock fall incident causing a vehicular accident at a rock cut location. The NHDOT continued to use its version of the RHRS, in addition to NYDOT's "factors", as part of its overall rock cut hazard assessment. The relative risk of a rock fall incident causing a vehicular accident was computed for rock cuts ranked only as "A" or "B".

In 1999, the NHDOT started to collect additional information during routine rock cut inspections. A digital camera was used to collect photographs of the rock cuts and a Global Positioning System (GPS) was used to acquire GPS points of the rock cut locations. The goal was to reduce the Bureau's film developing costs and to accurately locate each rock cut so they could be placed on a statewide map. In addition, two-dimensional profiles of selected rock cuts are being collected to provide data for future remediation projects and to model potential rock fall events with a computerized Rock Fall Simulation Program.

OBJECTIVE

In June of 2000, the NHDOT funded an in-house research project to develop a Geographical Information System (GIS) for the Geotechnical Section of the Bureau of Materials and Research. The primary focus of the research was to link together all existing and newly collected rock cut information, into one location, so it would be fully accessible to everyone within the NHDOT. Readily available computer hardware and software would be utilized to meet the project objective.

METHODOLOGY

Developing the Database

The original rock cut database software was not a relational database and was no longer supported by the Department. To achieve Department wide accessibility a new relational database was developed utilizing the Department's standard relational database software package. The new database is composed of thirteen tables, which store all the rock cut information. One main table is linked to twelve other tables, two of which have "one-to-one" relationships, while the other ten have "one-to-many" relationships. The main table contains information on location, rock type, construction method, year built, alignment, and local climate. The two tables with a "one-to-one" relationship are code tables for towns and counties. The remaining ten tables with "one-to-many" relationships contain hazard assessments, structural information and remediation cost estimates. Forms were developed for each of the tables to aid in data entry. Data is entered through a main form containing buttons to guide the user to the remaining forms (Figures 1-4). A query was developed to bring all pertinent information on each rock cut into one table for use within the GIS. Department wide access is obtained by placing the database on a networked global drive, which can be accessed by all NHDOT users.

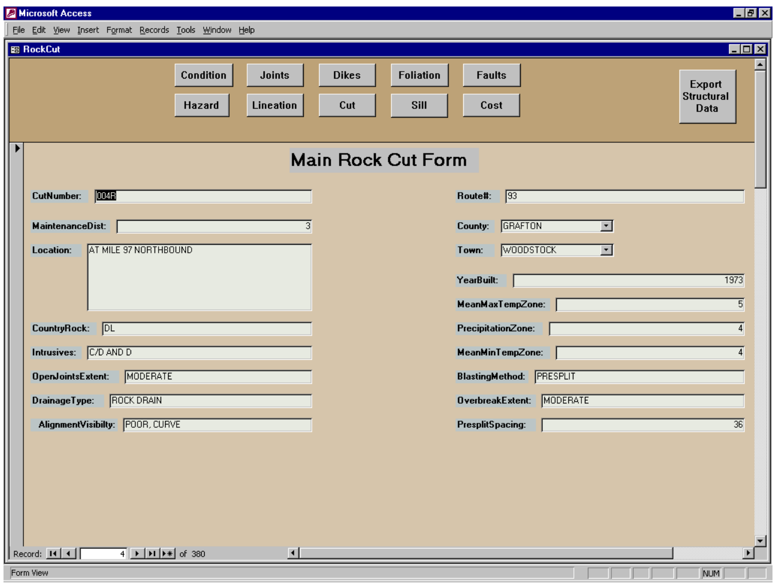

Figure 1. This is the Main Rock Cut Form where general information concerning the rock cut is entered. Buttons located on the form header automatically open the sub forms, which are linked to the Main Rock Cut Form by Cut Number.

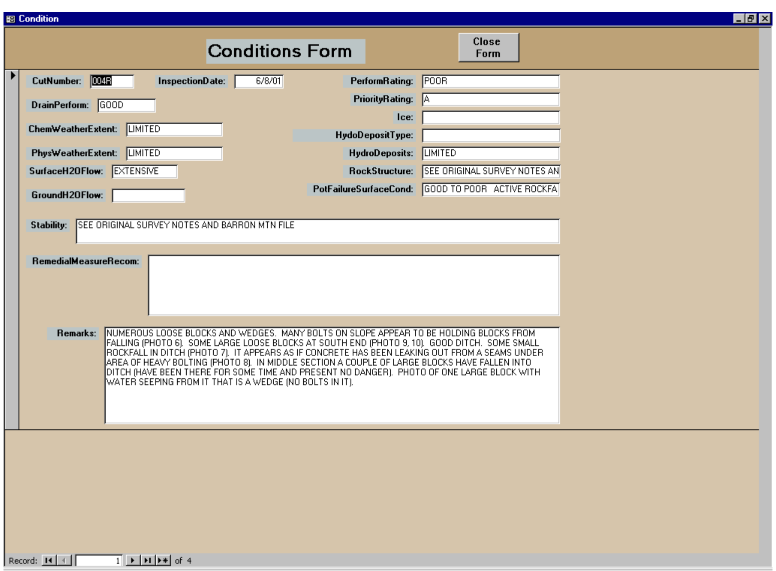

Figure 2. Information gathered while conducting routine inspections is entered into the Conditions Form. A preliminary priority rating is given to the rock cut based upon its previous rating and any changes that have occurred since the last inspection.

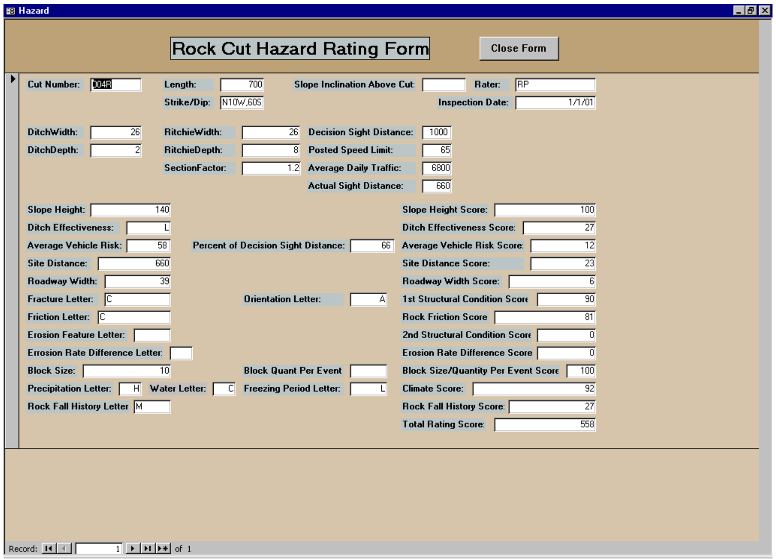

Figure 3. If a new hazard assessment needs to be done on a particular rock cut, the information is entered into this Rock Cut Hazard Rating Form and a Total Rating Score is determined for the rock cut.

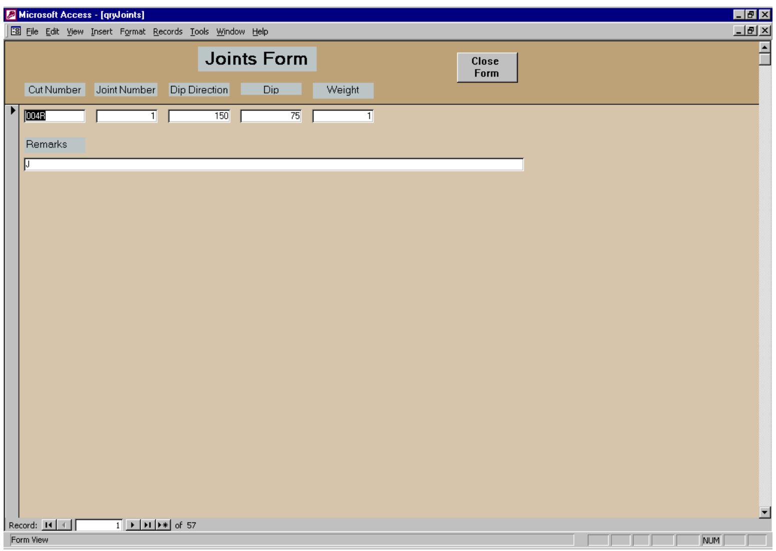

Figure 4. When structural data is collected on a rock cut, it is entered into the database using one of six structural data forms.

Enhancing the Database with GIS

A GIS is used to visually represent all the rock cut data. The GPS points, collected for the rock cuts, are combined and exported in a particular format, which can be brought into the GIS as a data layer. Based upon the rock cut hazard assessments each point can be color coded for degree of risk. Additional data layers can also be used to help locate the rock cuts and correlate data (i.e. town lines, roads, water bodies, topographic and geological maps). Through a structured query language (SQL) developed within the relational database, data can be transferred into the GIS and joined to the rock cut attribute table. New queries can then be developed within the GIS based upon all the data that was collected for each rock cut. The results of these queries can then be visually displayed on a map or within the current view of the GIS.

Tying Together Different Data and Media Types

The newly created GIS ties together numerous data types into one central location. Rock cut information, which was originally stored in an older database, has been exported into a new relational database. New information and previously collected data in paper files, has also been entered into the relational database. Because of the newly acquired GPS points, all the rock cut locations can be accurately placed on the statewide map. Digital photographs of every rock cut and graphical representations of all the structural data (rose diagrams, stereonets and density plots) were also placed into the GIS. To aid in rock cut remediation and rock fall simulation, two-dimensional profiles of selected rock slope faces were added into the GIS.

Collecting and Updating the Data

The rock cut structural data was collected using a Brunton compass and was converted to dip direction and dip angle for input into the relational database. Each structure type, including the orientation of the existing rock slope, was input into a specific table through a form. Once all the structural data was in the relational database it could be exported, in text format, by “clicking-on” a button. The stereonet program can read the text file and develop density plots, rose diagrams and stereonets by “clicking-on” the great circles (Figures 5 & 6).

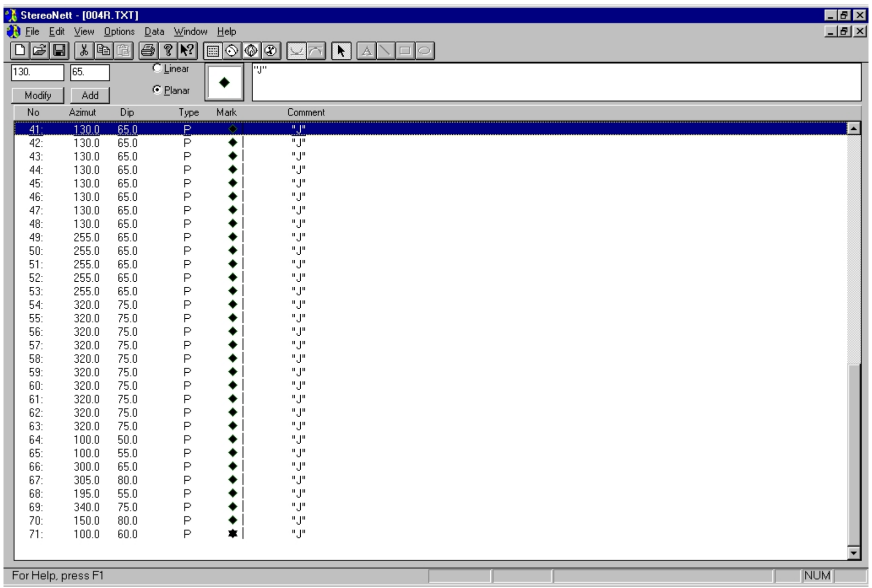

Figure 5. The structural data that was entered into the database is combined and exported in a format that is easily read by the stereonet program. This eliminates having to enter the data twice.

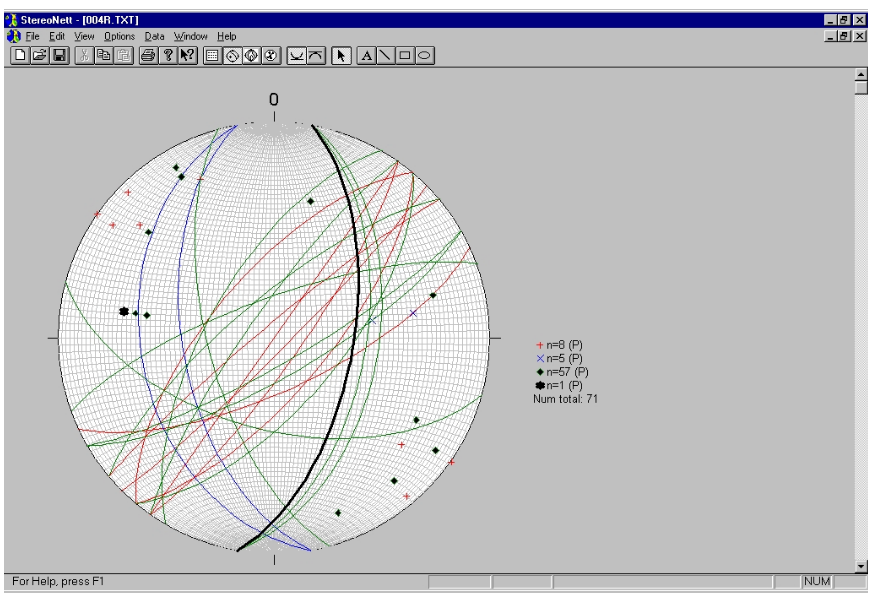

Figure 6. The stereonet, representing the structural data collected on the rock cut, can be selected by turning on the great circles and assigning a color, line width, and symbol to each type of structural condition.

A mapping grade GPS receiver, capable of obtaining real time sub-meter accuracy, is available for rock cut inspections. GPS points for several rock cuts can be obtained over the course of a day. Daily files are then combined into a single file and exported using a standard GPS processing software package.

Two-dimensional profiles are collected on rock cuts that are scheduled for remediation or have a potential for rock fall problems. The profiler is a laser gun and hand held computer linked together through a data cable and attached to a tripod. The location of each profile is obtained by using survey stationing or a GPS receiver (Figure 7).

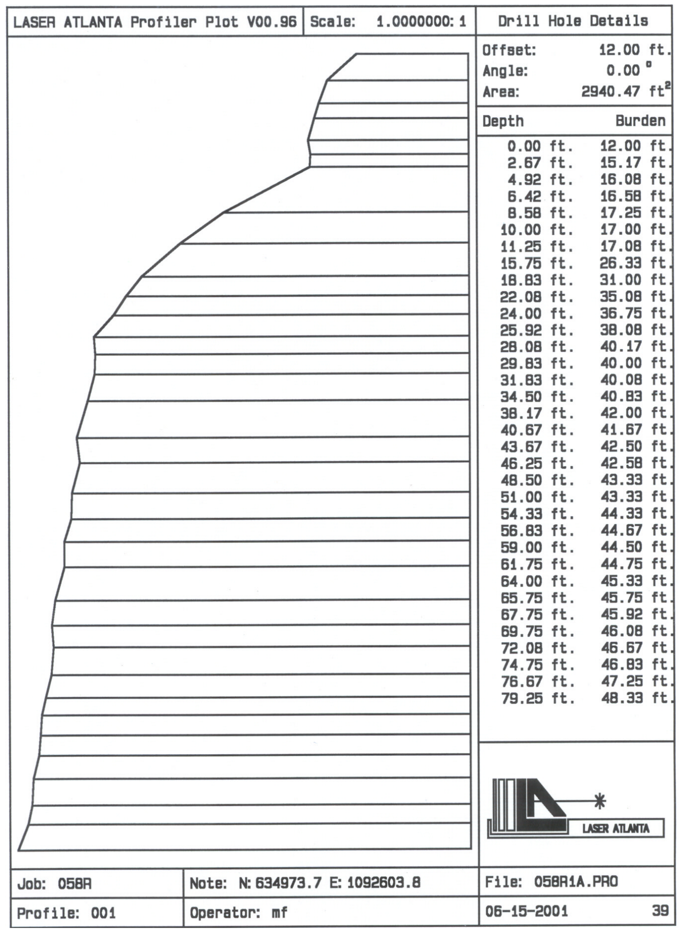

***Figure** 7. Two-dimensional profiles are collected on the rock cuts. Northing and Easting coordinates are collected using a GPS receiver, which indicates where each profile has been collected*

A series of digital photographs are taken of the rock cut while conducting routine rock cut inspections. Photographs include several overall views of the rock cut, which help in identifying or locating the rock cut in the field. Additional photographs may include the ditch area, water problems, the existing roadway, a profile view of the rock slope, existing rock fall, areas of differential weathering, potential failure surfaces, loose blocks, overhangs and wedges. The photographs are assigned the rock cut number plus a sequential number indicting the number of photographs for that particular rock cut. So the GIS can retrieve the photographs, they are placed within a specific directory.

A condition report is completed whenever a rock cut is inspected. The inspector will always walk the bottom of the cut and if needed the top of the cut. Items documented during the inspection might include a description of recent remedial work completed, changes in the rock slope (i.e. drainage, dimensions, slope angle, etc.), changes in the ditch, and a description of potential stability problems which could include recent slides or rock fall. Digital photographs are taken to document any recent rock fall or potential stability problems.

When remedial work or significant changes have occurred to the rock cut, a new hazard assessment must be completed utilizing the hazard assessment form. The new assessment would include collecting digital photographs, measuring new sight distances and ditch dimensions, obtaining updated traffic volumes, documenting new instability types with estimated rock fall sizes and quantities, and measuring the new rock cut dimensions. At the same time, new two-dimensional profiles and additional structural data may be collected.

RESULTS

Since the implementation of the GIS, rock cut information is no longer scattered throughout several different locations, only accessible to a few individuals. All paper files containing old data, information from inspection reports and revised measurements are now immediately available through the linked relational database within the Rock Cut Management System. By "clicking-on" the rock cut point feature a series of digital photographs for every rock cut can automatically be viewed within the GIS (Figure 8). Rock cut profiles, rose diagrams, stereonets and density plots can all be viewed using the same procedure. Simple queries can be developed using the "query builder" and their results visually displayed within the current view or on a map.

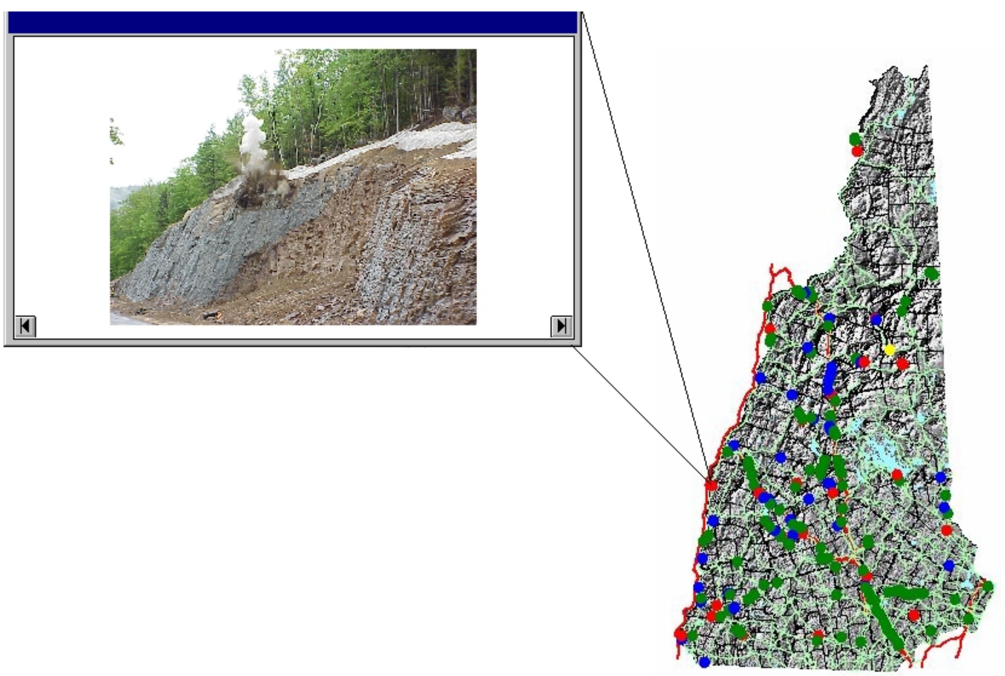

Figure 8*. By "clicking-on" the rock cut point feature, a series of digital photographs can be viewed within a specialized "pop-up" window. In a similar fashion, two-dimensional profiles and stereonets can be viewed.*

Three hundred and eighty rock cuts have been evaluated and are in the GIS. The size of the GIS changes every time a new rock cut is constructed or when an older rock cut is eliminated. All "A" and "B" cuts have hazard assessments, which are based upon the modified Oregon and New York systems. Many of the rock cuts have rose diagrams, stereonets and density plots and some have two-dimensional profiles.

The NHDOT Bureau of Planning houses the Department's GIS server. Multiple data layers, which have statewide coverage, can be obtained through this server. These data layers can be utilized as both base layers and secondary layers. All the information within the Rock Cut Management System, including secondary data layers, can be placed onto a base layer. Possible base layers might include: Topographic maps, aerial photographs, town and county polygons, bedrock and soils maps, and surficial geology maps. Secondary layers, which are placed on top of a base layer, might include: Roads and highways, town and county lines, glacial features, and water bodies. Both the base and secondary data layers can be used to help locate and describe the rock cut point features. A wide variety of maps can be made using the rock cut point features with different data layer combinations. For instance, all "A" rated rock cuts along a specific road, all rock cuts within a specific district, or all rock cuts with icing problems can be depicted (Figure's 9 & 10).

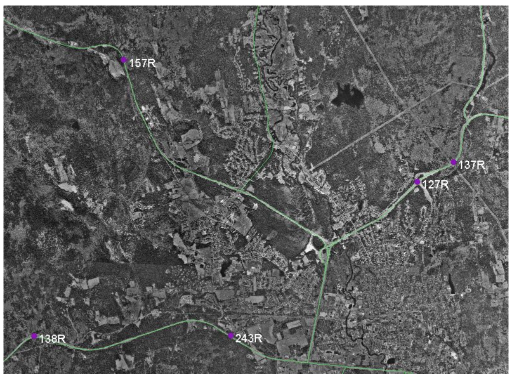

***Figure 9**. Aerial photography can be used as a base map for the Rock Cut GIS. The resolution is not high enough to see actual details on the rock cut. The secondary data layers (i.e. roads) can also be used to help locate the rock cut point features.*

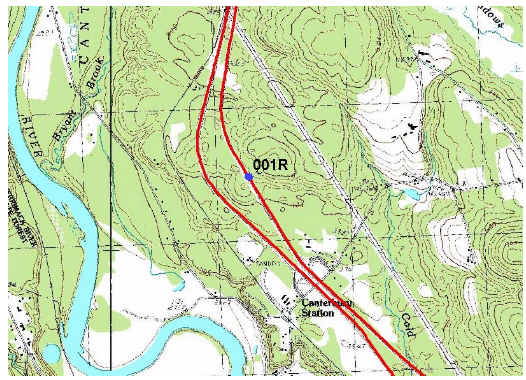

***Figure 10**. In addition to aerial photographs, USGS topographic maps can be used as base maps. Rivers and highways can also be used as secondary data layers to help locate the rock cut point features.*

LIMITATIONS

Hardware & Software Limitations

The hardware limitations are directly related to the network lines. Only so much data can be transferred over the network lines at any given time. The GIS server, with all the statewide coverage, is a separate server located in a different building from the server on which all the rock cut information is stored. Every user on the network uses a portion of a fractional T1 telephone line whenever they go onto the Internet or access files on a different server. Since most of the statewide coverage is contained in large files, long delays could occur when they are downloaded from the GIS server over the network lines. To minimize this problem, regularly used base maps and secondary data layers can be downloaded onto a hard drive and updated on a routine basis. The drawback to this approach is the amount of hard disk space that is required.

GIS software costs and licensing issues also present limitations. In order to have Departmental wide access to the Rock Cut Management System every potential user would need to have a GIS software license. The cost associated with this would be prohibitively high and not acceptable to the Department. Currently, only those users who posses the GIS software have the ability to access the entire Rock Cut GIS.

Data Interpretation

To interpret the geologic data and terminology within the database, individuals need training in geology and rock slope engineering. However, the data relating to location, visibility, rock cut number, priority rating, inspection date, stability, photographs, profiles and recommended remedial measures are beneficial to any user.

Data Quality

The GIS is only as good as the data that has been entered into it. Care needs to be taken to accurately enter the data from the field data sheets into the computer database. Only personnel specifically trained and knowledgeable in geological terminology should enter data into the GIS. Personnel conducting rock cut inspections need to be thoroughly trained in how to conduct a field inspection and how to operate the necessary equipment.

Maintaining a Current GIS

The collection of rock cut information is an ongoing process, which generates large volumes of data. Along with the regular rock cut inspection data, some data is being collected for the first time (i.e. geographical coordinates, profiles and digital photographs). All data needs to be combined with data previously gathered by others and entered into the database in a timely manner so the accuracy of the GIS can be maintained. If this does not occur, it becomes extremely difficult to track what data has been collected and where it has been stored.

CONCLUSIONS AND RECOMMENDATIONS

The process of adding newly collected and historical data into the Rock Cut Management System has been working well. For the first time, all the rock cut data can be viewed from one central location. Through the GIS, the data is visually displayed in a format that is easily understood. An endless number of questions can be asked of the data, in the form of queries, and then visually displayed within the current view. Correlations between rock cuts and locations can be extruded from the data and displayed on a map. Unfortunately, access to the Rock Cut Management System is only available to those possessing the necessary GIS software. Alternatively, the Rock Cut Database is available to everyone throughout the Department over the network lines and their database software.

To have Departmental wide access to the Rock Cut Management System, new software must be installed on the Department's GIS server. An Internet mapping software package would work well for this application. Through a web browser, users can access and display GIS data and images generated by others, as well as integrate data from multiple sources. This would eliminate the need for every user to have specialized GIS software installed on their personal computers. Since everyone within the Department has access to the Internet, they would be able to access all the maps and data associated with the Rock Cut Management System.

The biggest challenge will be keeping the GIS current. Every year some rock cuts are remediated or reconstructed, requiring new information to be collected and their hazard analysis to be updated. Routine rock cut inspections must be completed every year, where all "A" rated rock cuts require annual inspections, "B" rated rock cuts require inspections every three years and the inspection of "C" rated rock cuts every five years. This leads to a substantial amount of data being collected and entered into the computer database and GIS on a regular basis.

IMPLEMENTATION PLAN

The equipment & GIS described in this report has already played an important role in enhancing the Department's Rock Cut Management System. To fully implement this Rock Cut Management System, rock cut inspections need to occur on a regular basis and the Department needs to develop their capabilities in Internet mapping. In addition, the current equipment and computer software needs to be maintained and minor upgrades should be made.

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