Final Report

RDT 04-009

Development of a Highway Rock Cut Rating System For Missouri Highways

MISSOURI DEPARTMENT OF TRANSPORTATION
RESEARCH, DEVELOPMENT AND TECHNOLOGY

BY:

Dr. Norbert H. Maerz, Ph. D., P. Eng., Assistant Professor and Senior Investigator, Rock Mechanics and Explosives Research Center, University of Missouri-Rolla

Ahmed Youssef, Ph. D. Candidate, Department of Geological Engineering, University of Missouri-Rolla.

JEFFERSON CITY, MISSOURI
DATE SUBMITTED: March 2004

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. RDT 04-009	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Development of a Highway Rock Cut Rating System (MORFH RS) For Missouri Highways		5. Report Date March 2004 6. Performing Organization Code
7. Author(s) Norbert H. Maerz, Ahmed Youssef		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Missouri-Rolla 1006 Kingshighway Rolla, MO 65401		10. Work Unit No. 11. Contract or Grant No. RIO2-046
12. Sponsoring Agency Name and Address Missouri Department of Transportation Research, Development and Technology P. O. Box 270-Jefferson City, MO 65102		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes
The investigation was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract

MORFH RS (Missouri Rock Fall Hazard Rating System) is a new scheme for rating of rock fall hazards along the roads of the Missouri State Highway System. Existing rock fall hazard rating systems used in other States focus on the risk of failure and ignore the consequence of failure, or they lump the ratings for risk and consequence together. In MORFH RS, risk and consequence factors are given equal weight and isolated from each other. The ratings for the categories that relate to risk or consequence are easy to determine and are more objective. The risk – consequence rating system can be used by MODOT (Missouri Department of Transportation) to cost effectively determine the need and priority of remediation, and help facilitate the design of maintenance on rock cuts in order to provide for the safety and convenience of the motoring public by reducing the risk and consequence of falling and fallen rock to life and property.

17. Key Words Rock Hazard, Rock Fall, Rating System, Slope Maintenance, Risk Assessment, Video Logging, Image Measurements, GIS, Slope Stability, Rock Failure	18. Distribution Statement No restrictions. This document is available to the public through National Technical Information Center, Springfield, Virginia 22161

19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 231	22. Price

Form DOT F 1700.7 (06/98)

Executive Summary

MORFH RS (Missouri Rock Fall Hazard Rating System) is a new scheme for rating of rock fall hazards along the roads of the Missouri State Highway System. Existing rock fall hazard rating systems used in other States focus on the risk of failure and ignore the consequence of failure, or they lump the ratings for risk and consequence together. In MORFH RS, risk and consequence factors are given equal weight and isolated from each other. The ratings for the categories that relate to risk or consequence are easy to determine and are more objective. The risk – consequence rating system can be used by MODOT (Missouri Department of Transportation) to cost effectively determine the need and priority of remediation, and help facilitate the design of maintenance on rock cuts in order to provide for the safety and convenience of the motoring public by reducing the risk and consequence of falling and fallen rock to life and property.

MORFH RS utilizes two phases:

1. Identification of the most potentially problematic rock cuts, by using mobile digital video logging.
2. Using MORFH RS to characterize and prioritize remediation for the potentially problematic rock cuts identified in phase 1.

In phase 2 four types of parameters are evaluated:

1. Parameters such as slope height, slope angle, ditch width, ditch depth, shoulder width, block size, ditch capacity, and expected rock fall quantity can often be measured on computer scaled video images in the office.
2. Parameters such as weathering, face irregularities, face looseness, strength of rock face, water on the face, and design sight distance which are descriptive, and may need field evaluation.
3. Parameters such as average daily traffic, number of lanes, and average vehicle risk are obtained from the MODOT records for each section of road.
4. Conditional parameters such as adversely oriented discontinuities, karst features, ditch capacity exceedence, and the effect of bad benches.

Parameters were selected on the basis of ones that were deemed meaningful and/or relatively easy to measure or estimate. Parameters were assigned to either a risk or consequence category. In some cases a parameter was assigned to both.

MORFH RS has been tested on sections of Missouri Highways 63, 44, 65, 54, and other highways in Missouri. About 300 rock cuts were evaluated and used to prepare and modify the system. Parameter selection was done by careful consideration of a variety of parameters. Sensitivity analysis of the system was done by quantifying potential errors in the video measurements and by a rating comparison of 19 MODOT and UMR (University of Missouri-Rolla) personnel on 10 rock cuts along Highway 63.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Concept

The concept of this project was to develop and create a rating system for the Missouri Department of Transportation to facilitate investigations of the rock cuts along the highways. This rating system is based on rating risk-of-failure and consequence-of-failure under two separate categories. This allows independent assessment of risk and consequences. Probabilistic assessments could then be made which consider both aspects, such as "What is worse; high risk/low consequence or low risk/high consequence?" These are important considerations when attempting to prioritize projects during periods of funding austerity, when there are insufficient resources available to fund every project.

The risk and consequence factors could be combined (added, multiplied, divided) in some meaningful way to obtain a simple rating index. This index could then be divided by standard remediation costs to elicit a cost-benefit analysis of any particular site.

1.1.1 Risk factors

Risk factors are defined as measurable (or estimable) parameters that can be used as a predictor of the likelihood of failure. These are nominally geologic factors and the site's past history of rock falls. The following is a list of parameters that might be used:

1. Height (the higher the slope the less stable).
2. Slope angle (the steeper the slope, the less stable).
3. Rock face instability (how many historical failures on this section of road and rock type?).
4. Degree and depth of weathering (weathered rock is typically much weaker than un-weathered rock).
5. Strength of the materials on the rock face (weakest zone).
6. Face irregularity (blasting effectiveness).
7. Face looseness (scaling effectiveness).
8. Block size (good indicator of stability in absence of adversely oriented discontinuities).
9. Groundwater (seepage).
10. Adversely oriented discontinuities.
11. Karst effect.

1.1.2 Consequence factors

Consequence factors are defined as measurable (or estimable) parameters that can be used as a predictor of the consequence of failure. These are nominally highway and human factors that would predict the consequence of these failures:

1. Ditch capacity (width, shape, volume)
2. Expected rock fall quantities
3. Slope angle
4. Shoulder width
5. Number of lanes (if one lane is blocked by fallen rock, can the obstruction be safely avoided?).
6. AADT (Average annual traffic volume or design traffic index for new construction).
7. AVR (Average Vehicle Risk).
8. Decision sight distance
9. Block size

Figure 1 shows a conceptual example of how to combine risk and consequence by plotting both on a single graph. For example we might plot green symbols for stable rock cuts and red symbols for rock cuts with previous failure history. Once points are plotted over a broad range of rock cuts, empirical thresholds for stability will usually manifest themselves; these can then be used as rational guidelines for setting limits and action levels.

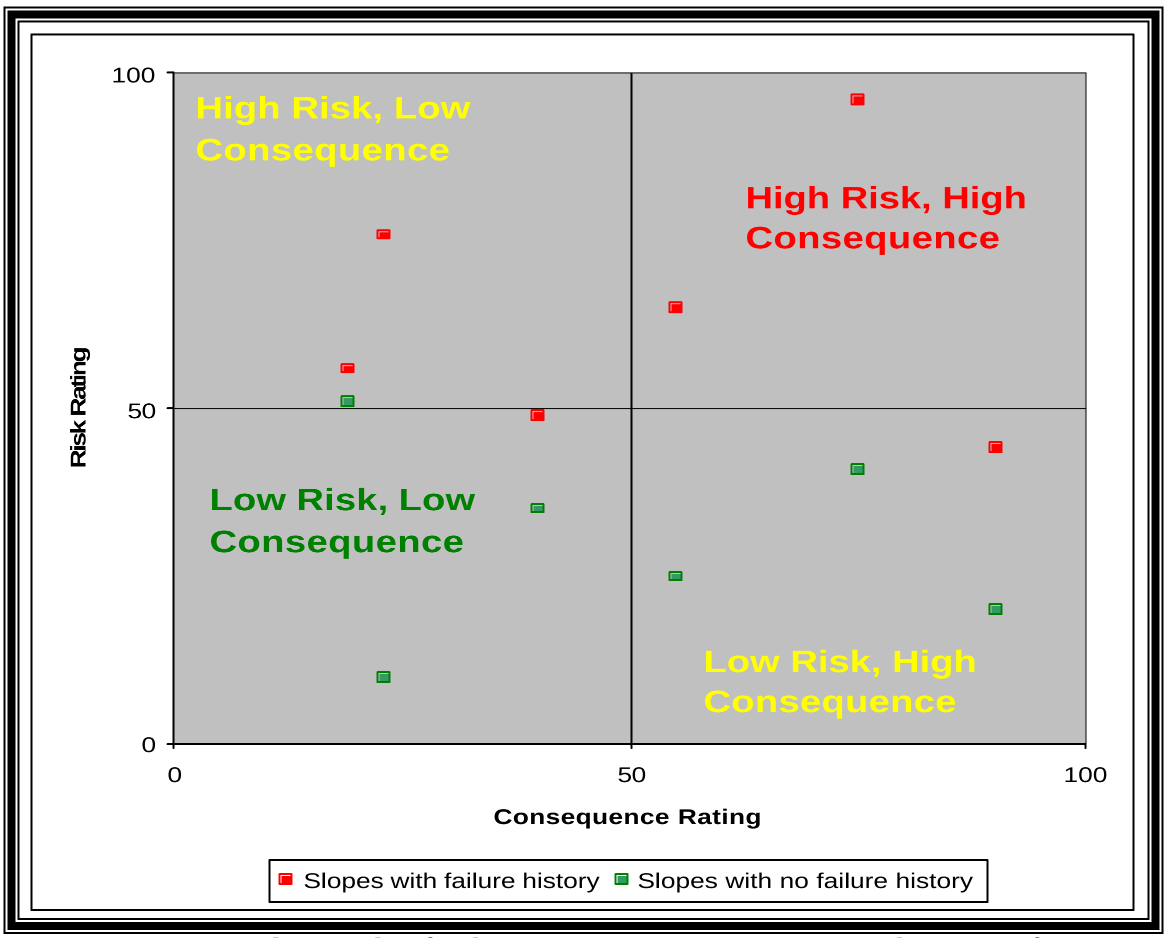


Figure 1: Conceptual example of risk/consequence assessment. Case histories of failed/stable slopes can be plotted on this graph to determine threshold action levels.

1.2 Literature review

1.2.1 Introduction

Rock cuts along roads and highways fail from time to time. Seismic (earthquake) activity or high groundwater pressures (after heavy downpours) can trigger large rock blocks or even larger assemblages of rock to crash down on the road surface below. Often the failed material is contained in the ditch. Sometimes, the material spills out onto the road and causes damage to the road surface or to vehicles traveling along the road. Infrequently injury and death to occupants of vehicles occurs.

Transportation highways in mountainous terrain require investigations and measurements to control the incidence of the rock falls and rock slope failure. Rock fall incidents range from minor falls that damage tires and body work to a large falls that severely damage vehicles, cause injuries and fatalities, result in economic loss due to closing the highways, and create a legal liability for the DOT. The Department of Transportation in California has extensively studied of the rock falls that occur along their highway systems to assess the causes and the effectiveness of the various remedial methods that have been implemented (McCauely et al. 1985). The Department of Transportation in California provide a useful guidelines on the stability conditions of rock slopes and the causes of falls; they studied about 308 rock falls on the highway systems and they found that the rock falls triggered by 14 different factors as in Table 1.

Table 1: Rock fall causes mechanisms, 308 cases, California Department of Transportation (McCauely et al., 1985).

Cause	Percentage of Total
Rain	30
Freeze – thaw	21
Fractured rock	12
Wind	12
Snowmelt	8
Channeled runoff	7
Adverse planner fracture	5
Burrowing animals	2
Differential erosion	1
Tree routs	0.6
Springs or seeps	0.6
Wild animals	0.3
Truck vibrations	0.3
Soil decomposition	0.3

CALDOT found that most of the rock falls happened in winter and these statistics are confirmed by Peckover (1975).

As a result, experienced professionals, using visual assessment and engineering judgment, typically do evaluations of rock cuts. Because there are thousands of miles of roads in most jurisdictions, the highly trained slope stability specialist spends too much of his time screening rock cuts, spending a disproportionate amount of his time looking at "safe" rock cuts, and not enough time designing remediation methods and priorities for "dangerous" rock cuts. Rock cut analysis tends to be a fairly informal process. A rock slope stability specialist, having determined by visual clues that the cut could benefit by remediation, identifies potential failure zones, determines the probability of failure as best he can, estimates the volumes of rock involved, and tries to predict the consequence of such a failure.

Work has been done in to select the priorities for prioritizing site remediation by Brawner and Wyllie (1975), Wyllie (1987), and Pierson et al. (1990).

To aid the specialist, classification schemes such as the RHRS (Rock fall Hazard Rating System) (NHI, 1993) can be used. Mitigation specifications (NHI, 1994; Piteau et al., 1979b) can be used. The problem with this approach is that the classification and specification is a time consuming process. While this process is justified for problematic rock cuts, it consumes too much time for rock cuts that may not be problematic.

1.2.2 Using image analysis in screening highway rock cuts

The concept of measuring features on video images taken from mobile platforms is not new. An example of such a system is described by Maerz and McKenna (1999). That system was designed for the measurement and inventorying of road signs. That sort of system is prohibitively expensive for this application, unless, as is the case for MODOT, one of these systems is in place for other purposes, and the existing data can be utilized. In the alternative, a much simple, cost effective imaging capability can be installed on any vehicle at a relatively low cost.

The measurement concept is based on trigonometric relationships between the vehicle direction vector, mean camera direction vector and the object vector in the image with respect to the mean camera direction vector, taken together with a series of constant vectors, such as the horizontal distance between the camera and the edge of the road, and vertical distance between the camera and the plane of the road. Were high accuracy measurements needed, these last two parameters would not be treated as constants, but would need to be quantified, as well as the attitude (pitch and roll) of the camera and vehicle. For the purpose of the moderately accurate measurements required for this proposal, these can be considered as constants. The method would require that position of the camera be calibrated, and that the geometric constants be entered into a database.

1.2.3 Rock fall rating systems

Every year during the rainy season rock falls take place in both natural and man-made slopes, especially along the road cuts of the hilly areas. These rock falls will not only block the roads, but also damage infrastructures cause injuries and fatalities, some of which remain unreported (Figures 2 and 3).

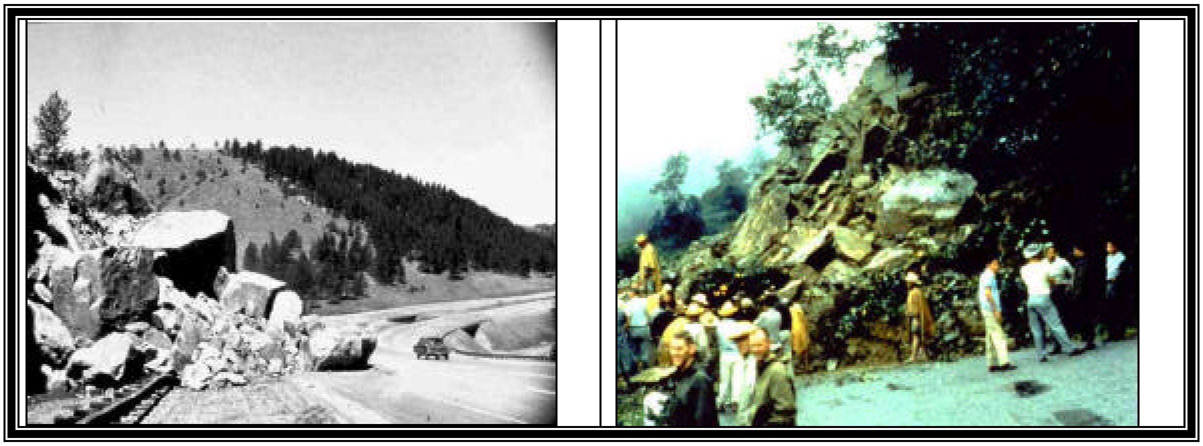


Figure 2: Example of rock failures causing obstructions in roadways

In order to manage this hazard, a detailed investigation is required to understand the causes, nature, distribution and other aspects of rock fall. However, most rock falls in the past were solely caused by the influence of natural factors. In this century, rock falls became more common due to the effects of anthropogenic activities such as road cuts, construction of large infrastructures, and quarries. Often the failed material is contained in ditches designed to contain the failed rock. Sometimes the material spills out onto the road and causes damage to the road surface or to vehicles traveling along the road.

Figure 3: Example of a rock failure causing fatalities

Piteau et al. (1979a), mentioned that predictive methods such as limiting equilibrium analysis are of little use where the primary structure of the rock is sub-horizontal bedding, and the secondary structure is sub-vertical joints. Rock fall is caused by many factors, including unfavorable rock structure (discontinuities), adverse ground water related conditions, poor blasting practices during original construction or reconstruction, climatic changes, weathering and tree levering (Brawner, 1994).

__1.2.3.1 Planar, wedge sliding and toppling analysis.__
In many areas the discontinuities are oriented in such a way that they contribute to create wedge, planar sliding, or toppling failures (Figure 4).

Planar failures occur along prevalent and/or continuous joints dipping towards the slope, with strike near parallel to the slope face. There are two conditions that govern the instability: First that the critical joints dip less than the angle of the slope; and, second when the shear strength in the joint is not enough to assure stability. The planar failures depend on the continuity of the joint. The size of planer failure ranges from a few cubic meters to large scale landslides. A documented example is that of the K M mountain landslide in the state of Washington (Lowell 1990), controlled by the bedding orientation.

Wedge failures occur along two joints of different orientations whose line of intersection dips toward the slope. This type of failure is more frequent than plane failure. The formation and occurrence of wedge failures are dependent primarily on lithology and the structure of rock mass (Piteau, 1972).

Toppling failures occur when prevalent and/or continuous family of joints which dip into the slope with a strike near parallel to the slope face.

Figure 4: Example of wedge, planar, and toppling failures along highway rock cuts.

Simple block and wedge pull-out failures are easy to analyze with limit equilibrium analyses and numerical modeling (Hoek and Bray, 1981; Piteau, 1979c; Piteau, 1979d). Piteau and Martin 1982 mentioned that the most common method employed is the simple limiting equilibrium technique to evaluate the sensitivity of possible failure conditions to slope geometry and rock mass parameters. Kinematic analysis based on the orientation of the combination of discontinuities, the slope face, the upper slope surface, and any other slope surface of interest together with friction that is examined to determine if certain modes of failure can possibly occur. This analysis is normally conducted with the aid of a stereographic representation of the planes and /or lines of intersect (Markland 1972). There are some advantages and disadvantages for this type of analysis.

Advantages:

1. Easy to analyze by using limiting equilibrium analysis, numerical modeling, and by using simple methods as stereonet plotting (kinematic analysis).
2. It is easy to predict the failure modes
3. Design for remediation and/or mitigation are easy

Limitations:

1. These types of failure modes are not always the controlling one, and sometimes are very hard to predict if there are hidden joints behind the rock face.
2. There are many types of failures that can not be analyzed by using equations.
3. Does not take into account rolling and bouncing blocks.

1.2.3.2 Raveling type of failure modes

Most of the damaging highway rock falls are not simple blocks and wedges, and are more difficult to analyze. Badger and Lowell (1983) summarized the experience of the Washington State Department of Highways. They stated that ‘A significant number of accidents and nearly a half dozen fatalities have occurred because of rock falls in the last 30 years and 45 percent of all unstable slope problems are rock fall related. Also, Hungr and Evans (1989) note that, in Canada, there have been 13 rock fall deaths in the past 87 years. Almost all of these deaths have been on the mountain highways of British Columbia.

On the other hand, Franklin and Senior (1997b) reported that of 415 analyzed rock slope failures along highways in Northern Ontario, only 33% of those involved toppling or planar blocks and wedges; 67% of the rock slide incidents that were identified involved mechanisms that were more complex (Table 1). In terrain underlain by flat lying sedimentary rock with vertical orthogonal jointing, planar and wedge slides are usually absent, with the predominant failure mechanism being raveling (Figure 5). Raveling can be difficult to recognize a-priori because it involves time-dependency.

Table 2: Road cut failure types, 415 cases, Ontario study (Franklin and Senior, 1997b).

	Failure Modes	Proportion of Failures
Easy to Analyze	Toppling	23%
	Planar Sliding	8%
	Wedge Sliding	2%
Difficult to Analyze	Raveling	25%
	Overhang	15%
	Ice Jacking	14%
	Rolling Blocks	12%

Figure 5: Examples of raveling, undercutting, and bouncing and rolling failures along highway rock cuts.

If 67% of the rock slope failure mechanisms are difficult to analyze using conventional engineering block kinematic methods, a rock fall hazard rating system may be the only workable mechanism to help identify problems and then develop a remediation plan and a maintenance schedule for highway rock cuts.

These types of failures are ubiquitous. There is no single factor that controls the failure, and manifestations include raveling, overhang/undercutting failure, ice jacking, rolling and bouncing of the materials on the slopes. Failures are complex and difficult to analyze, because there are few methods of analysis and models to rely. Models such as the Colorado rock fall simulation program provide some opportunity for consequence determination but arte somewhat inexact.

1.2.3.3 Empirical Design

In some terrains with predominantly flat lying sedimentary rock such as in Missouri, these types of failures dominate. Remediation designs are typically made on the basis of empirical engineering judgment, by an experienced specialist.

Attributes of the empirical design method include:

1. Assessment of the risk of falling, rolling and bouncing rocks.
2. Remediation of the risk of falling, rolling and bouncing rocks, by scaling and supporting the rock.
3. Assessment of the consequence of falling, rolling and bouncing rocks.
4. Mitigation of the consequence of falling, rolling, and bouncing rocks, by designing slope angles and catchment systems.

The empirical design method does not use formal design methods and calculations, or analytical equations, but relies on the experience and judgment of the engineer.

Traditionally design method and data analysis can vary greatly from engineer to engineer, and that knowledge and ability is difficult to transfer.

A more rigorous way of formalizing empirical design is to us a classification system of some type. A rock slope can be classified in terms of several to many parameters that are easy to measure or estimate and are useful as predictors of rock behavior. Specific design elements can be associated with specific classification ratings. Thus:

1. Much of the engineering experience can be built into the system, and is not limited by the experience of individual engineers.
2. Collecting data and classifying the rock cuts is specified in a meaningful way and consistent way.

The best methods for screening rock cuts are the classification systems because they provide the ability to rapidly screen rock cuts and separate out the ones that are fundamentally sound, and identify the ones that have potential problems (Maerz, et al. 2003).

1.2.3.4 Examples of pure rock mass classification systems

Rock mass classification and empirical design schemes have the following in common:

1. Description of ground quality by a quantitative classification system, based on parameters that are easily and universally measured.
2. Description of ground performance by a formal set of parameters (unsupported standup time, support requirements, bearing capacity, ease of excavation, etc.).
3. Correlation of the ground quality and performance, either based on a broad spectrum of case histories or local and/or global experience.

Rock mass classifications form the backbone of the empirical design approach which relates practical experience gained on previous projects to the conditions anticipated at a proposed site. In most projects, the classification approach serves as the only systematic and practical basis for the design of rock excavations and slope designs. Rock masses are classified for different factors as follow:

1. Identify the most significant parameters influencing the behavior of a rock mass.
2. Divide a particular rock mass formation into a number of rock mass classes of varying quality.
3. Provide a basis for understanding the characteristics of each rock mass class.
4. Derive the quantitative data for engineering design
5. Recommend support guidelines for a design.
6. Provide a common basis for a communication between an engineer and a geologist.
7. To relate the experience on rock conditions at one site to other sites.

There are many examples for these classification systems that include elements of design:

1. Deere's RQD (Rock Quality Designation) system (Deere et al., 1969; Deere and Deere, 1988).
2. Franklin's Size-Strength system (Franklin, 1986).
3. Franklin's Shale Rating System (Franklin, 1983).
4. Bieniawski's RMR (Rock Mass Rating) system (Bieniawski, 1984)
5. Bieniawski's Engineering Rock Mass Classifications (Bieniawski, 1989)
6. Barton's Q system (Barton et al., 1974).
7. Singh and Goel, (1999), a system for rating rock masses in the mining and tunneling industries.
8. Romana's SMR (Slope Mass Rating) system is for rock slopes, based on Bieniawski's RMR system (Romana, 1985).

The limitation of these systems is that they consider geological factors only, and are essentially classifying risk only.

1.2.3.5 Classification considering rainfall as well as geologic factors

The Rock Engineering system (RES) methodology, devised by the Rock Engine Group of the Department of Earth Resources Engineering of the Imperial College of Science, Technology and Medicine, University of London is described by Hudson (1992), Hudson and Harrison (1992) and Mazzoccola and Hudson (1996). It uses the following parameters for the analysis of slope instability: Lithology, folding, rainfall, previous instability, rock strength, weathering, slope orientation, slope height, slope angle, compaction, rock discontinuities, vicinity to faults, and hydraulic conditions

Limitations of this system include not being able to distinguish between stable and unstable slopes based on field inspection, and no ability to consider the consequence of failure.

The rock mass instability index RMIIj was developed by Ali, M. K and Hassan, K. (1999) who studied the landslides in Bangladesh. The research work was based on a thorough field investigation which was followed by geomathematical analyses of the collected field data. They developed a new method to determine the degree of instability of slopes quantitatively, according to the cause and effect for each parameter in the RES. They use the following equation for determine the RMIIj:

$$RMII_j = \sum_{j=1}^{j=25} a_i . P_{ij}$$

Where: i refers to parameters,
j refers to slopes,
a_i is a scaled value from C + E diagram,
P_{ij} is a rating value assigned to different classes of values of each parameter and its different for different slopes (i.e. the jth slope).

By using this new method the slopes can be quantitatively distinguished by their degree of instability, in which higher values of RMIIj indicate higher degrees of slope instability.

Limitations of this system include the limitation of the RES system, and this method can be applied on landslides and not on rock falls.

1.2.3.6 Rock Hazard Rating Systems - RHR

There are many rock hazard rating systems that are designed for highway cuts, and consider more than just geological factors.

The Oregon's RHR (Rock Hazard Rating) System was designed specifically for highway cuts in Oregon (Pierson and Van Vickle, 1993). The Oregon system was designed for the relatively high cuts in the mountainous areas of Oregon because it was felt these were more dangerous. The detailed rating system uses 10 categories with 4 nominal rating criteria and scores, although interpolations of scores between criteria are allowed. They use 10 factors for the rating (Table 2).

Table 3: RHR categories for evaluation of rock slope rating (Pierson et Al., 1993).

1. Slope height (25, 50, 75, or 100 feet),
2. Ditch effectiveness (good, moderate, limited, or no catchment),
3. Average vehicle risk (vehicle present in rock fall section 25, 50, 75, or 100% of the time),
4. Sight distance (100, 80, 60, or 40% of stopping distance when viewing a 6" object),
5. Roadway width (44, 36, 28, or 20 feet including shoulders),
6. Structural condition **discontinuous rock** (discontinuous joints- favorable orientation, discontinuous joints – random orientation, discontinuous joints – adverse orientation, or continuous joint – adverse orientation),
7. Rock friction (rough –irregular, undulating, planar, clay infilling or slickensided),

or

7. Structural conditions eroded rock (few differential erosion features, occasional

erosion features, many erosion features, or major erosion features),
8. Difference in erosion rates (small, moderate, large – favorable structure, or large – unfavorable structure),
9. Block size/volume of rock fall event (1/3, 2/6, 3/9, or 4/12 ft/cubic yards),
10. Climate and presence of water on slope (low to moderate precipitation; no freezing periods; no water on slope, moderate precipitation or short freezing periods or intermittent water on slope, high precipitation or freezing periods or continual water on slope, or high precipitation and long freezing periods or continual water on slope and long freezing periods,
11. Rock fall history (few, occasional, many, or constant falls).

The advantages of the RHR system, designed to deal with rock falls along road cuts and rail lines, is that it goes much further than other classification systems, using material properties, rock fall history, volumes of material that might fail, and the capacity of existing ditch area. The system uses a screening technique, allowing high-risk slopes to be quickly identified by a preliminary rating (A,B,C).

The limitations of the RHR system include the fact that the system is not very sensitive for small heights of rock cuts, consequently not being a universal system, best suited for very rugged terrain. The system also considers the consequence of failures, classifying such parameters as ditch effectiveness, average vehicle risk, sight distance, and roadway width; however it does not attempt to separate risk and consequence in any way.

1.2.3.7 Rock Hazard Rating Systems - RHRON

The Ontario RHRON (Rock Hazard Rating ONtario) is a modification of the Oregon system, designed for less mountainous terrains. Ontario's glaciated topography is much more subdued than Oregon, with lower cut slope heights. Oregon's RHR system was just not sensitive enough to be useful. Franklin and Senior (1997b) attempted to address the overemphasis on high slopes and large volumes of debris that occur when using Oregon's power relationship between rating and score. In this system they added five new parameters and several parameters were re-defined. The following formula was used to determine the RHR value

$$RHRON\ (\%) = (F1 + F2 + F3 + F4) * \frac{100}{36}$$

in which: F1=Magnitude: "How much rock is unstable?"
F2=Instability: "How soon or often is it likely to come down?"
F3=Reach: "What are the chances of this rock reaching the highway?"
F4=Consequence: "How serious are the consequences of the blockage?"

For the preliminary screening, each of these F factors is directly rated on a scale of 0 to 9. For the detailed rating, each of these F factors is calculated from a number of individual ratings, also on a scale of 0-9.

$$F1 = \frac{(R2 + R3 + R4))}{3}$$

$$F2_{ravelling} = \frac{(R1 + R9 + R11 + R4 + R5 + R6))}{6}$$

$$F2_{sliding} = \frac{(R1 + R9 + R11 + R5 + R6 + R8))}{6}$$

$$F2_{erosion} = \frac{(R1 + R9 + R11 + R4 + R7 + R10))}{6}$$

$$F3 = \frac{(R4 + R13 + R16 + R19)}{4}$$

$$F4 = \frac{(R17 + R18 + R19))}{3}$$

Where:

R1=History of rock falls
R2=Volume of the largest potential rock fall
R3=Volume of total potential rock fall
R4=Face irregularity
R5=Face looseness
R6=Joint orientation/persistence
R7=Rock intact strength
R8=Rock joint shear strength
R9=Block size
R10=Slake durability
R11=Water table height
R12= Slope height
R13=Crest angle
R14=Ditch and shoulder width
R15=Ditch capacity
R16=Overspill potential
R17=Average vehicle risk
R18=Decision sight distance
R19=Available paved width
R20=Remediation cost

Not all rating factors are used in all cases and some ratings are used for different purposes entirely, such as calculating cost-benefit ratios.

The advantages of the RHRON system are that it is more comprehensive, and more sensitive to less extreme rock cuts.

The system is somewhat arbitrary, and limitations include the lack of separation between risk factors and consequence factors, the time consuming nature of gathering the data, and the fact that some factors need laboratory testing.

1.2.3.8 Rock Hazard Rating Systems - New York Rock Slope Rating Procedure

The New York DOT developed their own rating system for rock fall hazard (NYDOT, 1996). This system use three factors: Geologic, section and human exposure for computing the relative risk of a rock fall, using this formula as a total relative risk:

$$\text{Total Relative Risk} = GF * SF * HEF$$

Where: GF is the geological factor
SF is the section factor
HEF is the human exposure factor.

The geological factor considers the properties of the rock slope, and the value of GF depends on the slope specific geologic and physical characteristics. The GF (geological factor) uses 6 categories (geology, block size, rock friction, water/ice, rock fall, and back slope) with 5 nominal rating criteria and scores. The scoring is a power progression, with score $y=3^X$ where x is a rating between 1 and 5 and allows scores of 1, 3, 9, 27, and 81 respectively.

The SF (section factor) considers the risk that fallen rock would actually reach the highway lanes and it is depending on the geometry of ditch and shoulder to the rock slope offset. SF is computed as the ratio of required Ritchie criteria to actual dimensions, the following equation represent how can we calculate the SF.

$$SF = (DR+WR) / (DA + WA)$$

Where: DR is the idealized ditch depth
WR is the idealized ditch width
DA is the actual ditch depth
WA is the actual distance between toe and pavement edge/shoulder.

The principle is based on retaining bouncing and rolling rock, and DR, WR consider slope heights and angles.

The HEF (human exposure factor) considers both active condition (moving vehicle hit by falling rock or hitting newly fallen rock) and passive condition, for moving vehicle hitting rock that has been on the highway for some time. The active condition is:

$$F_a = AADT \times [(L+SSD)/V \times 24{,}000)]$$

Where: AADT is the average annual traffic
L is the length of the rock fall zone
SSD is the stopping sight distance
V is the travel velocity.

The limitations of this system are the insensitivity to small slopes and the inability to separate risk and consequence factors. In addition, the connection between the rated GF, and more analytical SF and HEF is ambiguous and may be tenuous.

1.2.4 Karst effects

1.2.4.1 Introduction

Karst is formed by the dissolution of limestone and dolomite (carbonate rocks), salt beds, by the groundwater (Unklesbay and Vineyard 1992). Beck and Sayed (1991) mentioned that karst is a distinctive topography resulting from geological weathering and erosion processes of soluble carbonate rocks that are overlain by unconsolidated sediments.

Karst conditions are a dominant problem along the highways of Missouri. This study was done to understand the effect of different types of karst features on the risk of failure of rock cuts. The study ranged from reconnaissance investigations to identify possible areas of karst, to detailed investigations including rating system to determine the Risk-Consequence effect for the sinkhole zone.

The karst features along Missouri highways from very narrow dissolution fractures to very wide sinkholes, typically infilled, with fill strength properties ranging from soft loose soils, to very well compacted materials, from fine grained materials to large boulders surrounded by weak cement as clay and shale materials. This study utilized a wide range of investigations including field reconnaissance, measurements of the dimension of the sinkholes, material type, and the rating parameters for these karst features.

The results of this integrated information provided the highway design engineers with the necessary data for developing a good remediation method to decrease the effect of the presence karst features along the Highways.

1.2.4.2 Karst and Sinkholes in Missouri Rock Cuts

The most abundant rocks in Missouri are the carbonate rocks. The limestone and dolomite are composed of materials that easily dissolve in acidic ground water and form karst features.

Collapsed caves and sinkholes are the common examples of karst. These may range from less than 1 foot to more than a few hundred feet in diameter. Their depths may vary over the same range, while their position and length may extend over an area of considerable extent. Along the road cuts caves or sinkholes are filled by sediment (sand, clay, shale) (Figure 6) or falling native rock blocks from the adjacent walls and ceilings of the cave (Figure 7).

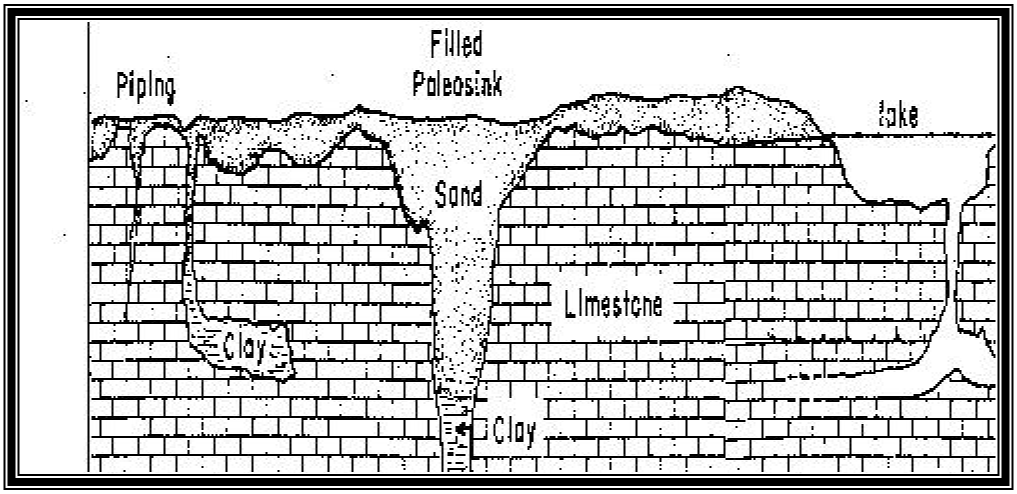


Figure 6: Sketch shows a sinkhole and fractured solution filled by sands and clay.

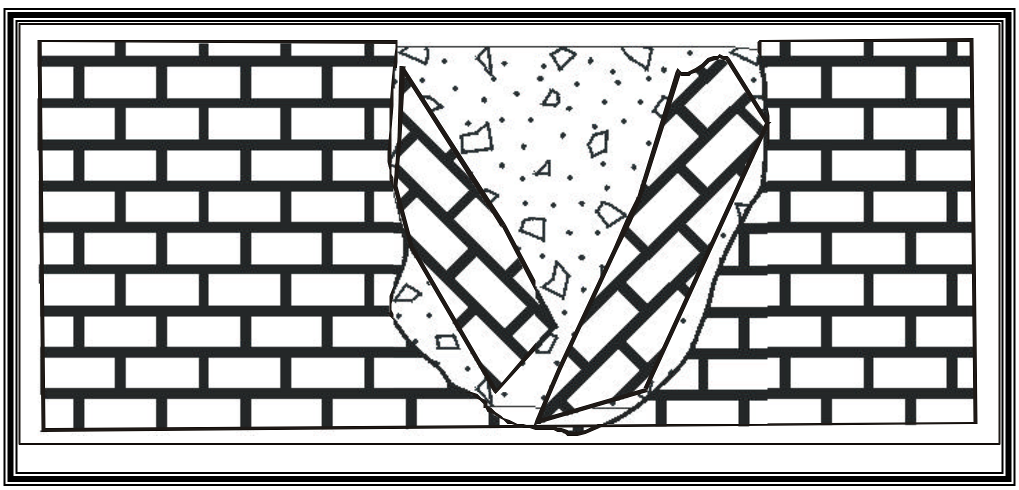


Figure 7: Sketch shows a collapsed cave structure filled by rock boulders and cobbles, typically highly weathered.

1.2.5 Bench effects

The benching of tall slopes is one of the most effective methods to ensure that falling rock from the top of the cut does not reach the highway. The bench itself is a reserved area for catching (restraining) rocks that detach from the upper. There are many bench related parameters that affect bench face stability:

1. Bench height.
2. Bench face intact strength.
3. Shear strength of discontinuities.
4. Intact rock strength.
5. Discontinuity orientations by set.

6. Estimated joint persistence and spacing.
7. Perceived purpose of the bench face.

When designing rock cut slope angles, the following need to be considered:

1. The slope must be as steep as possible in order to maintain excavation quantities and minimize the cost.
2. The overall slope angle must be cut back sufficiently as related to the geological characteristics of the rocks, such as discontinuity orientations, weathering, etc.
3. The design must seek to mitigate the effects of fallen rock, by containment such as in ditches or on benches.

Accordingly, there are three main kinds of slope design which are used for highway excavations

1. A uniform slope from ditch line to the top of the slope.
2. A slope consisting of a series of slope segments at different angles.
3. A slope consisting of vertical segments separated by horizontal benches.

Although benching increases slope stability, the most important part of the design in this application is the mitigation of the consequence of falling rock. As such benched designs are superior to non-vertical slopes.

Bench designs are based on three variables:

1. Width of benches.
2. Vertical height between benches.
3. The slope angle between benches.

For shale and similar rocks, the erosion problem is reduced by use of a bench design because of the reduction of velocity of water that moves down the sloping exposures and onto the bench. Also the slopes between benches can be steeper because falling rock will be intercepted by the benches. The proper location of the benches is directly related to the character and variability of the rock.

Many engineers consider that the benches are "clean off areas", meaning that the debris and fallen rocks will need to be removed periodically, thus making room for additional weathering materials (Edwin, B. E., 1958).

Another factor that must be considered in designing the benches is the direction of the transverse slope on the bench itself. It is recommended that the bench should be sloped away from the road to prevent the falling blocks from reaching the road and longitudinal drains along the inner edge of the bench and face avoid accumulation of water in the slope (Edwin, B. E., 1958).

If the engineering design is mandated neither by regulation, economics, nor safety concerns, then the following should be considered (James Mathis, course 2003):

1. Identify potential failure modes.
2. Determine the dip for the geologic structures that may on occasion.
3. Calculate the stability of the potential individual failure blocks by using a suitable method.
4. Adjust the bench face angle until an appropriate safety factor is realized against sliding and/or
5. Calculate reinforcement for the sliding blocks

There are many attempts by many authors to understand the bench effect and how to design them. The first major effort in determining the required catch bench width was conducted by Arthur M. Ritchie, of the Washington State Highway Commission, in the early 1960's. It utilized many good concepts including video recording of rock trajectories and the rotational behavior of rock in flight between bounces. Most importantly, hundreds, if not thousands of physical tests were conducted to determine the actual run-out distance of rock traveling down a variety of slope angles with varying slope conditions. From the design chart that Ritchie prepared we can determine a required bench width (Ritchie, A.M. 1963). The required bench width is that which is required to 'catch' and hold a very large percentage of rolling rocks originating from the bench face above the catch bench. Design bench width is the bench width that is laid out for excavation. This will include the required bench width plus some additional amount for back break.

Mechanics of rock falls

Most rock falls are generally initiated by some event that causes a change in the forces acting on a rock. These factors include increase of pore water pressure due to rainfall, weathering and erosion of surrounding material during heavy rain storms, freeze-thaw processes in cold areas, chemical degradation or weathering of the rock, root growth or leverage by roots moving in high winds. As soon as the movement of a rock perched on the top of a slope face has been initiated, the important factor controlling the fall trajectory of the falling blocks is the geometry of the slope. Non-vertical slope faces, the dip on the slope face will produce a horizontal component to the path taken by a rock after it bounces on the slope or rolls off the slope. The most dangerous situation of these are when surfaces act as “ski jumps” and impart a high horizontal velocity to the falling rock, causing it to bounce a long way out from the toe of the slope. Clean and un-weathered faces are the most dangerous because they do not retard the energy of the falling or rolling rock to any significant degree. However, surfaces covered in talus and debris materials like gravel absorb a considerable amount of the energy of the falling rock and, in many cases, will stop it completely (Hoek, E. 2000).

With the advent of computer programs that simulate bouncing/rolling rock on a slope, the ability to statistically design the required bench width took a major step forward. Most of the computer programs that deal with the trajectories of the falling rocks have retarding capacity of the surface material, which expressed mathematically by a term called the coefficient of restitution. This coefficient depends upon the nature of the materials that form the impact surface. Clean surfaces have high coefficients of restitution while soil, gravel and completely decomposed rocks have low coefficients of restitution. That is why the gravel layers are placed on catch benches in order to prevent further bouncing of falling rocks. Size and shape of the rock boulders, the coefficients of friction of the rock surfaces and whether or not the rock breaks into smaller pieces on impact are other factors that will have significant effect on the trajectories of the falling blocks. Consequently, there are many computer programs written by different people to predict the rock fall trajectory and simulate them, these models are very effective and important in the design of rock cuts, such as the program written by Hoek (Hoek. 1986), (Piteau 1980) and (Wu 1984). More refined models produce better results, provided that realistic input information is available. Some of these models are recent, as those of Bozzolo et al., (1988), Descoeudes and Zimmerman 1987, Spang 1987, Hungr and Evansm, (1989), Spang and Rautenstrauch, (1988), Pfeiffer and Bowen 1989, Pfeiffer et al. 1990, and Azzoni et al., (1995). These models are capable of producing reasonably accurate predictions of rock fall trajectories. Most of these rock fall models include a Monte Carlo simulation technique to deal with the variable in the parameters that included in the analysis.

Given such software, we can include the actual bench profile as well as the variability of the bench crest as determined by our statistical bench face design process. While this doesn't include every lump and bump on the actual bench face that may affect the final trajectory of an individual rock, it goes a very long way to allowing optimization of the design catch bench width. An example is given in Figures 8a, b, and c. Here, the difference is shown between a horizontal bench, a horizontal bench with a berm and a reverse inclined bench. Instead of utilizing the reliability of the bench width as a design criterion, we can now directly utilize the percentage of rock escaping the bench. Fixing this level of "escape" is the designer's and operator's responsibility. It is situation and input data dependent (James Mathis, short course 2003).

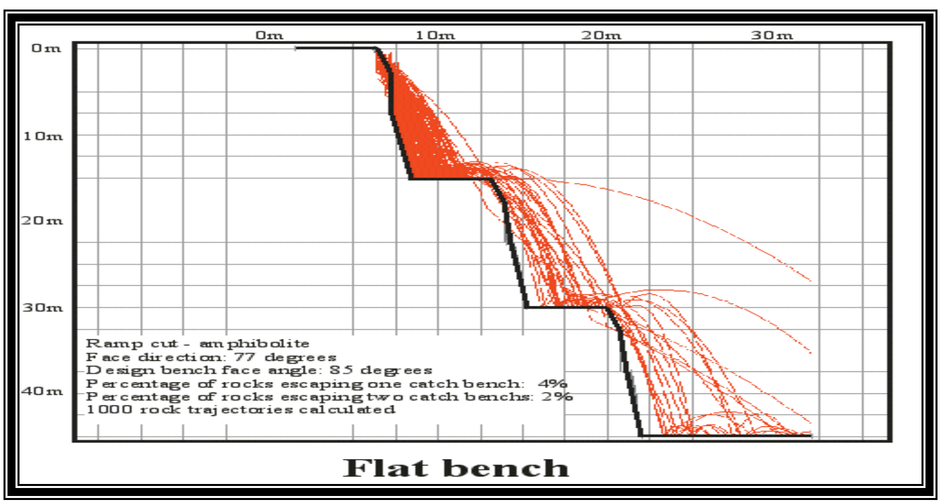


Figure 8a: Rolling rock study for a flat bench ... from design comparisons performed with the program ROCFALL

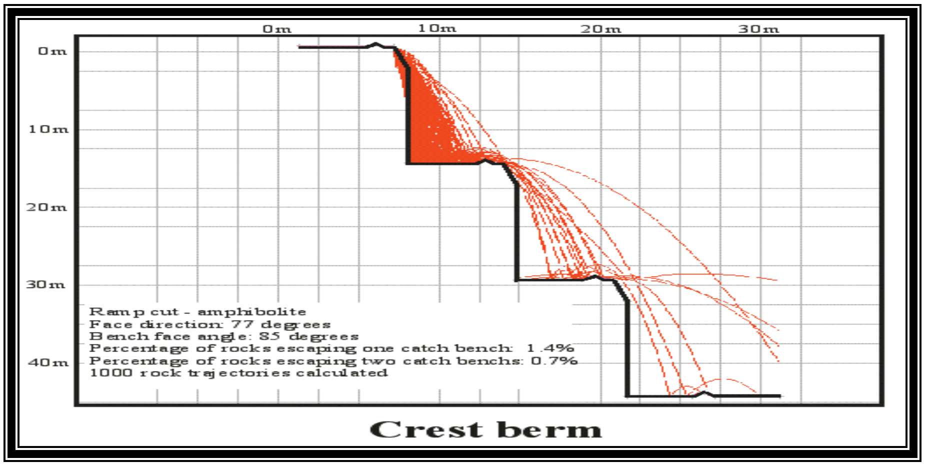


Figure 8b: Rolling rock study for a crest berm bench ... from design comparisons performed with the program ROCFALL.

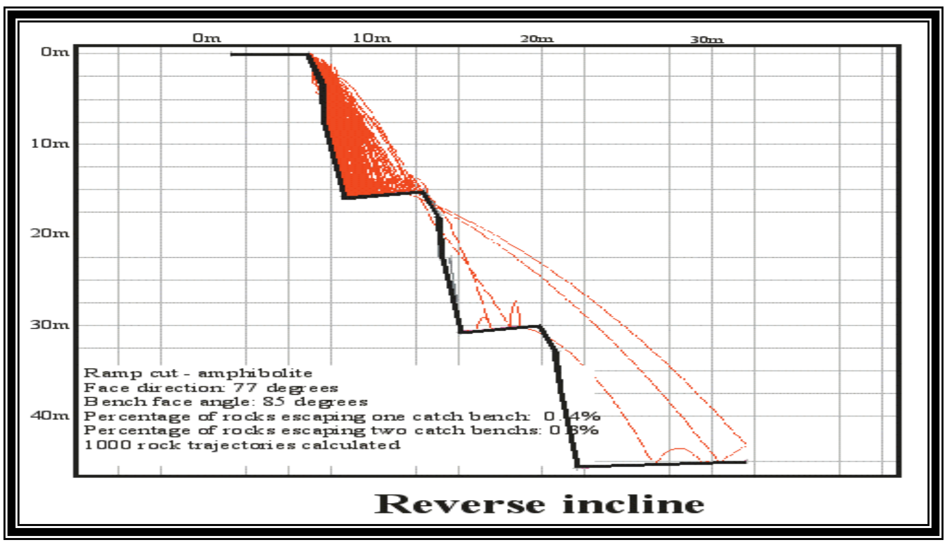


Figure 8c: Rolling rock study for a reverse incline bench ... from design comparisons performed with the program ROCFALL.

For the design of highway cuts in a rock mass with horizontal bedding Bukovansky, et al., (1975) suggest that vertical cut faces interrupted by horizontal benches are a logical solution. In this case benches can significantly reduce or eliminate the rock fall hazard. But in the modern design for highway cuts the rock fall hazard problem can be solved by using a single wide catchment bench at the toe of the cut (Ritchie,. 1963). But due to the severe fracturing of the rock strata and potential for toppling failures, intermediate benches were believed to be necessarily (Bukovansky, et al., 1975).

1.3 Acknowledgments

The authors would like to acknowledge the Missouri Department of Transportation (MODOT) for funding this research. We would especially like to thank Tom Fennessey, Mike Fritz, George Davis, Alan Miller, Rob Lauer, and Ray Purvis of MODOT for their help in providing guidance for this project. We would like to thank the University of Missouri System Research Board for the original seed funding of this research, especially the development of the RockSee program. Also we would like to thank the MODOT personnel and the students of the Geological Engineering Department at UMR for their help to verify the system. Also, we would like to thanks The World Laboratory (Switzerland) for funding Ahmed Youssef in developing the early parts of the RockSee program.

2. Objectives

2.1 Contract objectives

The objective of this work is to develop a rock hazard rating system for Missouri highway rock cuts. There are some specific objectives in this work as:

1. Research existing rock hazard rating systems.
2. Determine which rock cut measures or parameters are important as predictors of risk, consequent, and cost of remediation, in consultation with Missouri DOT personnel.
3. Determine which rock cut measures or parameters are easy to measure (are conducive to a workable data collection scheme) using observation of Missouri rock cuts and in consultation with Missouri DOT personnel.
4. Determine the combination of parameters (subject to 2 and 3) to classify different types of risk, consequence, and costs of remediation.
5. Develop a system to take the measurements and predict maintenance requirements.
6. Test the system on several Missouri highway rock cut sites.

2.2 Plan of action

There are six tasks in the plan for this work as follow:-

2.2.1 Task I: Literature review

The first task will be to review all available literature on rock hazard rating systems, including publications by users of such systems as well as the developers.

2.2.2 Task II: Identifying parameters

This task will identify all measurable parameters that could become a rock hazard rating system. These will largely be based on the RHRON system, but will also need to take into account the uniqueness of Missouri rock cuts. It is anticipated that some new parameters will be used to deal with the high weather cuts and filled sinkholes that are often found in Missouri rock cuts. Decisions will be made in consultation with Missouri DOT personnel, and using field observations as a guideline.

2.2.3 Task III: Selection of parameters

This task will narrow the list of parameters down to those that are deemed meaningful and relatively easy to measure or estimate. For each parameter, ranked values perhaps on a scale of 0-9 will be established. This too will be done in consultation with Missouri DOT personnel and field observations.

2.2.4 Task IV: Arrangement of parameters

This task will group the parameters into groups that pertain specifically to risk, consequence, and cost of remediation. Some parameters will be assigned to one group, some perhaps to 2 or 3 groups. Ratings within each group will be determined by some formulation of each of the ranked value parameters.

2.2.5 Task V: Rationalization of groups

This task will take the rankings from each of the groups (risk, consequence, and cost) and combine them to determine an "urgency of maintenance/remediation" value. As examples, a high priority maintenance/remediation recommendation could be as a result of: 1) high risk; 2) moderate risk combined with high consequence; or 3) moderate risk, moderate consequences combined with low remediation cost. A low priority maintenance/remediation recommendation could be as a result of: 1) low risk; 2) low consequence; or 3) moderate risk, moderate consequences combined with high remediation cost.

2.2.6 Task VI: Field testing

On advice from Missouri DOT personnel, up to 10 typical rock cut sites in Missouri, preferably in the Central to Southeastern Missouri will be selected for complete assessment, in order to test and fine tune the rock hazard rating system.

3. Present Conditions

3.1 State of the art of rock hazard rating in the nation

Rock fall hazard rating is becoming an issue in many states, as described in section 1.2.3. From a totally reactive approach to rock falls some states are getting proactive, adapting or developing rating systems. This allows them to prioritize remediation of rock cuts, and schedule maintenance in a systematic way.

3.2 State of the art of rock hazard rating in Missouri

Proactive rock fall hazard rating is currently not being used in Missouri at this time. The MORFH RS system being developed here will remedy this situation.

4. Technical Approach

4.1 Preparatory work

Preparation for the field work to develop the MORFH RS systems included:

1. Preparation for the field maps, Acquisition of field equipment (clinometers, compass, measuring wheel, mount video camera, and GPS).
2. Design and updating the field data sheet.
3. Development and acquisition of office tools (VCR to screen the movies, Adobe Premiere 6 to convert the movie to AVI format, and the RockSee program for measurements.
4. Digital video logging of some sections of highways, using and inexpensive setup (Figure 9) to determine representative site locations.
5. Making measurements on the digital images of the representative site locations

4.2 Field procedures

Many rock cuts were investigated in the field. Observations were conducted to identify potential parameters for MORFH RS, and to establish threshold values of these parameters. Rock cuts were located using GPS coordinates (Figure 10).

The data was collected in phases to prepare the rating system, when improvements were made to the rating system, the rock cuts were re-examines. Data sheets were prepared; Figure 11 shows the final version of the field data sheet.

Figure 9: Digital (Mini-DV) camcorder mounted on vehicle dashboard.

Figure 10: GPS (global positioning system) used to get coordinate data for each site.

A	Site NO.		**B**	Latitude	
C	Highway		**D**	Longitude	
E	Mile reference		**F**	Elevation	
G	Bench	Yes No if yes look at the faces above the bench			
1	Faces above bench	SCORE 12 6 0 Weathering High Low Fresh Face irregularity High Moderate Smooth Face looseness Large Moderate No Bench width Narrow<5ft Moderate 15 ft Wide >20 Rock on the bench Large amount Moderate No Slope of the bench Back slope Horizontal Toward road TOTAL SCORE: If less than 36 then bench is bad			
	Bench is	Good bad	If bad	Overall Slope ^	
2	Slope height	Ft	**3**	Slope angle	
4	Rock fall instability	4 3 2 1 0 C unstable – Unstable - Partially stable – Stable – Completely stable			
5	Weathering	4 3 2 1 0 High – Moderate – Low – Slightly – Fresh			
6	Strength factor (for the weakest zone)	4 3 2 1 0 Very strong – Strong – Moderate – Weak – Very weak			
7	Face Irregularities	4 3 2 1 0 Very high – High – Moderate – Slightly – Smooth			
8	Face Looseness	4 3 2 1 0 Very high – High – Moderate – Few – No			
9	Block size	Average discontinuity spacing ft			
10	Water on slope	0 1 2 3 4 Dry – Damp – Wet – Dripping – Flowing			
11	Ditch width	Ft	11’	Ditch depth	Ft
12	Ditch Volume	Cu ft/ft	13	Shoulder width	Ft
14	Number Of Lanes		15	ADT	Car/day
16	Expected RFQ.	Area of the face Depth of loose materials			
17	AVR	Speed Limit = m/hr Rock cut Length = ft			
18	DSD	3 2 1 0 Very Limited – Limited – Moderate – Adequate			
19	Adjust. Factor	Discontinuity adversity No Fair Unfavorable Very unfavorable <20 20-45 45-65 >65			
20	Adjust. Factor	Karst effect 4 3 2 1 0 Width 150 ft 100 ft 50ft carbonates non-carbonates Materials Boulders/ cobbles in weak cement			
21	Ditch Shape If bad bench Or slope < 90°	3 2 1 0 Flat Slight back slope Moderate back slope Large back slope 0° 1V: 8H 7° 1V: 6H 9° 1V: 4H 14°			
	Pictures				

Figure 11: Rock cut description chart

4.3 Office procedures

The following describes typical office procedures, after the video logging was done.

1. Screening the rock cuts along the highways using the video movies. Figure 12 shows the DV (Digital Video) tape deck used to transfer the rock cut movies to the computer using Adobe Premiere 6 (Figure 13) to transfer and edit the digital video, which is saved in AVI format.
2. Determining which cuts were to be used and required detailed on-site ratings.
3. Acquiring all possible measurements from the video image for each site using the RockSee program (Figure 14).

After the field rating had been done:

4. Entering all the data on the Excel rating sheet to generate the risk and consequence values.
5. Plotting the risk- consequence values on the graph to graphically display the rating.

Figure 15 shows a flow chart for the entire process.

Figure 12: Digital Video (DV) recorder to transfer the movie from DV mini tape to computer.

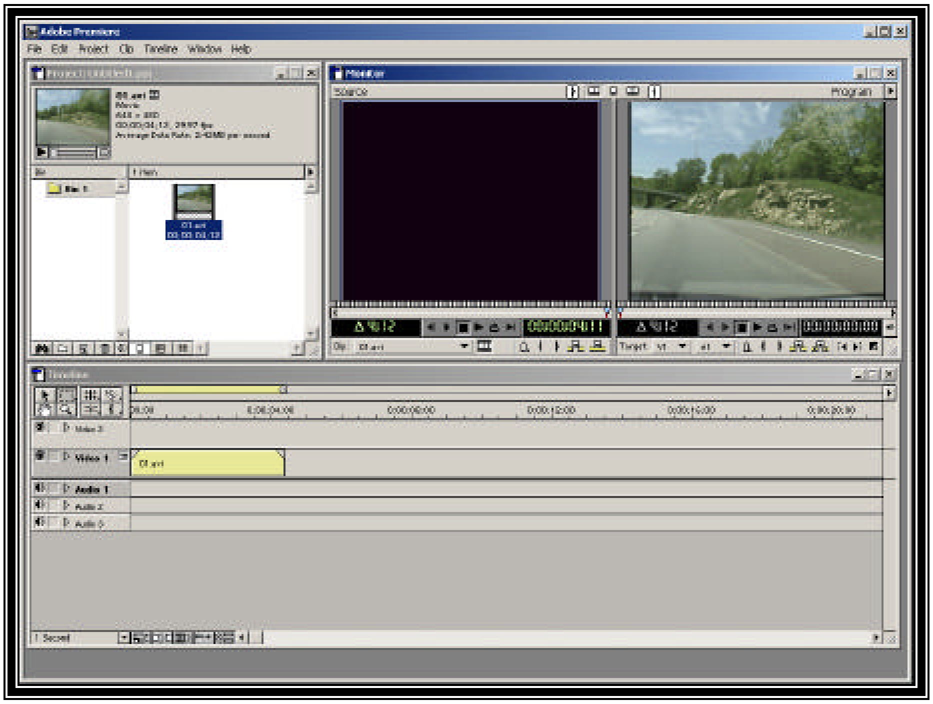


Figure 13: Adobe Premiere 6 program interface used to transfer the rock cut videos to the computer.

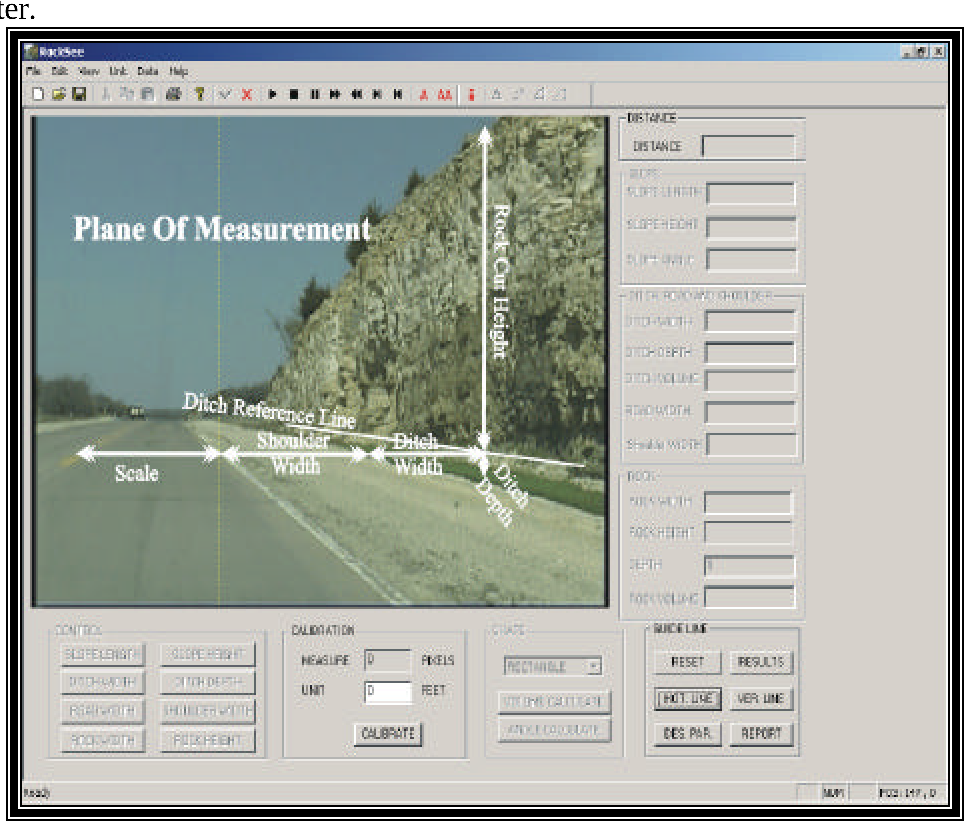


Figure 14: RockSee program to measure various parameters needed for the hazard rating system. Typical measurements include slope heights, lengths, and angles; ditch widths, depths, and volumes; mass volumes; and other linear measures.

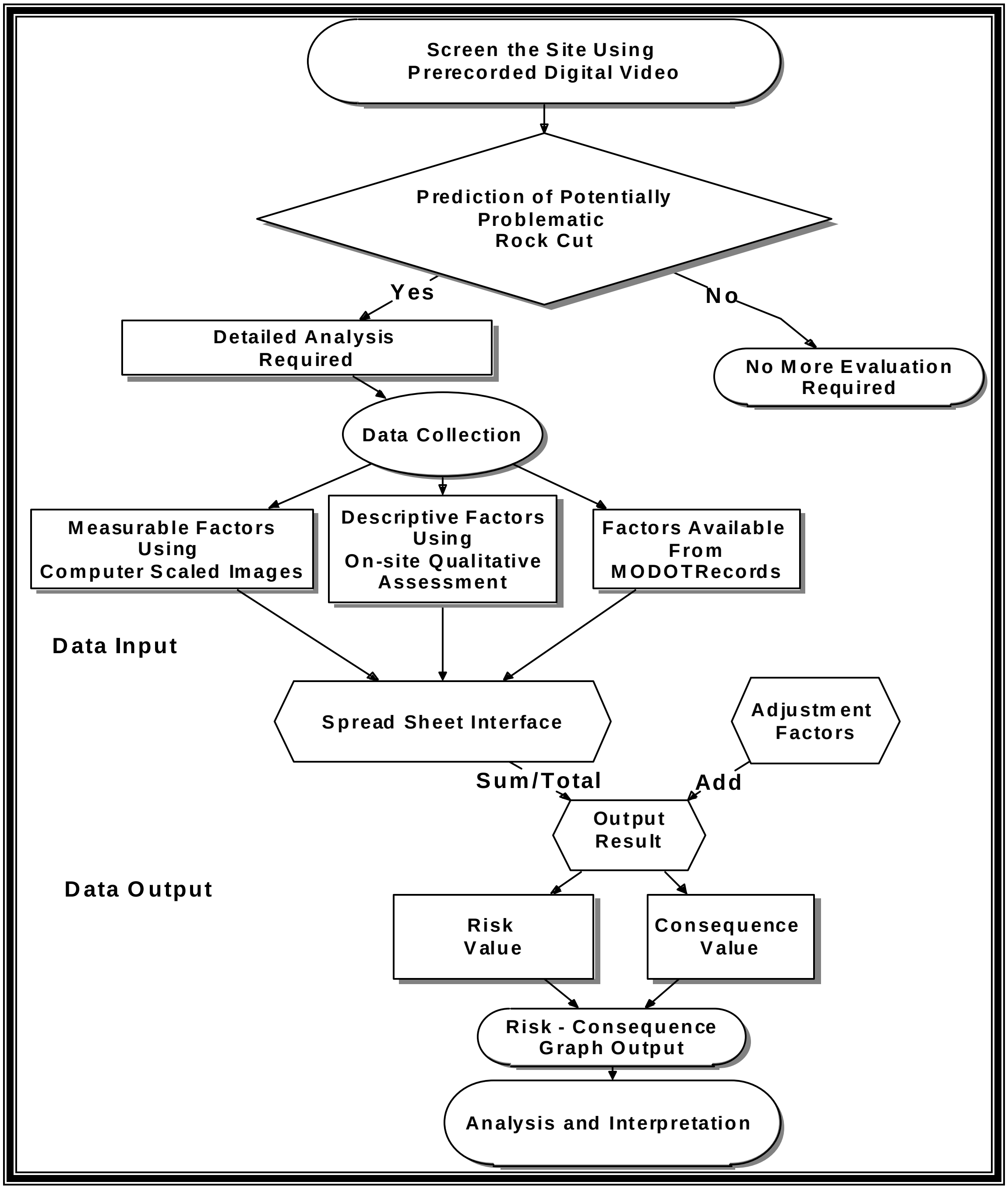


Figure 15: Flow chart showing how the system works.

4.4 Data processing methods

For the data processing the four types of parameters used in the system are put into the rating system, both on the risk side and consequence side. The parameter types are:

1. Parameters that can be measured on the images,
2. Parameters that are rated in the field,

3. Parameters that can be obtained from the DOT/or determined a-priori in other ways.
4. Conditional parameters that are rated in the field, depending on conditions observed.

Three methods were used to present the results:

1. Manual calculations and plots.
2. Microsoft Word® user interface, with and embedded Microsoft Excel® OLE® objects.
3. RockSee program used to determine the risk- consequence values.

4.5 Preliminary Ratings

4.5.1 Introduction

The MORFH RS requires a preliminary assessment or screening rating to determine whether or not a detailed (site) investigation is required. The criteria here is that the preliminary rating must be simple, quick, and it must be done from the video log. If there is any doubt, the conservative assumption to do a detailed (site) investigation should be made.

The proposed factors listed below are selected based on ease of evaluation from video images.

4.5.2 Rules/ factors that are important to determine which rock cuts need detailed ratings

4.5.2.1 Weathering / Karst evidence

A detailed assessment will be triggered by any of the following:

1. A highly weathered rating on the video image (Figure 1).
2. Any indication of Karst (voids, filled sinks).
3. Any significant differential erosion (cut back voids, overhangs).

4.5.2.2 Face Irregularity/Face Looseness

A detailed assessment will be triggered by any of the following:

1. A highly irregular face or a moderately irregular face high on the cut (Figure 2).
2. A highly loose face or a moderately loose face high on the cut (Figure 3).

4.5.2.3 Fallen rock in the ditch or on the cut.

If significant quantities of fallen rock (more than a few pieces, or more than a small pile) are to be seen on the image, a detailed assessment will be triggered (Figure 4).

4.5.2.4 Ditch effectiveness

If the ditch effectiveness is very low (Figure 5) either because it is too small, too narrow, or filled with loose rock, a detailed assessment will be triggered.

4.5.2.5 Adversely oriented discontinuities

If there is any evidence of adversely oriented discontinuities, a detailed assessment will be triggered.

4.5.2.6 Benches

If benches are found that are narrow, slope toward the highway, have loose material on them, or weathered/irregular surfaces above them (figure 6), a detailed assessment will be triggered.

Indication for weathering

Indication for karst

Indication for weathering

No indication for weathering or karst

Figure 16: Examples of different indication features for weathering and karst.

Indication for face irregularities	No indication for face irregularities

Figure 17: Examples of different indication features for face irregularities.

Indication for face looseness	Indication for face looseness

Figure 18: Examples of different indication features for face looseness.

Indication for blocks on the face	Indication for blocks in the ditch

Figure 19: Examples of different indication features for blocks in ditch and on the face.

Ditch effectiveness is very low (small to no ditch width and small to no ditch depth)

Ditch effectiveness is very good (wide ditch > 30 ft and very deep 3 ft)

Figure 20: Examples of ditches with different features for ditch effectiveness.

Bench slopes toward the Highway

Very narrow bench width

Figure 21: Examples of poor benches.

4.5.2.7 Slope Height

Notwithstanding the previous criteria, no detailed assessment will be done if:
1. The slope height is less than 10 feet.
2. The slope height is less than the width of the ditch plus the shoulder.

5. Results and Discussion (Evaluation)

5.1 MORFH RS Risk-Consequence Parameters

5.1.1 Introduction
This section describes the parameters of the MORFH RS.

5.1.2 Parameters
1. Slope Height (SH)
2. Slope Angle (SA)
3. Ditch Width (normal and modified) (DW)
4. Ditch Shape (DS)
5. Ditch Volume (DV)
6. Expected Rock fall Quantities (ERFQ)
7. Shoulder Width (SW)
8. Number Of Lanes (NOL)
9. Average Daily Traffic (ADT)
10. Average Vehicle Risk. (AVR) (Using rock cut length, number of cars per day, posted speed limit, and number of lanes)
11. Block Size (BS)
12. Adverse Discontinuities adversity (AD)
13. Ditch Capacity (calculated) (ERFQ/DV)
14. Rock fall Instability (RFI)
15. Weathering Factor (WF)
16. Strength of the Intact Rock (SOIR)
17. Face Irregularity (mechanically) (FI)
18. Face Looseness (FL)
19. Water On Face (WOF)
20. Decision Sight Distance (DSD)
21. Karst effect (KE)
22. Benches Factor (BF)
23. Slope Factor (SF)

5.1.3 Parameter classification by type
There are four categories of parameters, arrange by how the parameter is evaluated. Complete descriptions are given in Section 5.1.5.

5.1.3.1 Parameters that can be measured on digital images

1. Slope Height (SH)
2. Slope Angle (SA)
3. Ditch Width (DW)
4. Ditch Shape (DS)
5. Ditch Volume (DV)
6. Expected Rock fall Quantities (ERFQ)
7. Shoulder Width (SW)
8. Average Vehicle Risk. (AVR) (Using rock cut length, number of cars per day, posted speed limit, and number of lanes)
9. Block Size (BS)

5.1.3.2 Parameters that are rated in the field

10. Rock Instability (RI)
11. Weathering Factor (WF)
12. Strength of the intact rocks (SOIR)
13. Face Irregularity (FI)
14. Face Looseness (FL)
15. Water On Face (WOF)
16. Decision Sight Distance (DSD)

5.1.3.3 Parameters that can be obtained from the DOT/or calculated internally

17. Number Of Lanes (NOL)
18. Average Daily Traffic (ADT)
19. Ditch Capacity (calculated) (ERFQ/DV)

5.1.3.4 Conditional parameters that can be rated in the field

20. Karst effect (KE)
21. Benches Factor (BF)
22. Slope Factor (SF)
23. Adverse Discontinuities (AD)

5.1.4 Parameter classification by risk or consequence

Each parameter is used either towards the risk classification or the consequence classification. Some parameters are used in both risk and consequence classifications; however a parameter might have a negative effect on classification and a positive effect on the other. Complete descriptions are given in Section 5.1.5.

5.1.4.1 Parameters that are routinely used for risk assessment

1. Slope Height (SH)
2. Slope Angle (SA)
3. Rock Instability (RI)
4. Weathering Factor (WF)
5. Strength of the intact rocks (SOIR)
6. Face Irregularity (FI)
7. Face Looseness (FL)
8. Block Size (BS)
9. Water On Face (WOF)

5.1.4.2 Parameters that are routinely used for consequence assessment

10. Ditch Width (DW)
11. Ditch Shape (DS)
12. Ditch Volume (DV)
13. Expected Rock fall Quantities (ERFQ)
14. Shoulder Width (SW)
15. Number Of Lanes (NOL)
16. Average Daily Traffic (ADT)
17. Average Vehicle Risk. (AVR) (Using rock cut length, number of cars per day, posted speed limit, and number of lanes)
18. Decision Sight Distance (DSD)

5.1.4.3 Parameters that are conditionally used for risk assessment

19. Adversely Oriented Discontinuities (AOD)
20. Karst Effect (KE)

5.1.4.4 Parameters that are conditionally used for consequence assessment

21. Ditch Capacity Exceedence (DCE=ERFQ/DV)
22. Bench Factor (BF)
23. Slope Factor (SF)

5.1.5 Parameter descriptions

5.1.5.1 Slope height (SH)

Description and significance

The slope height category evaluates the risk associated with the height of a slope. High slopes have a greater risk of failure than lower slopes. Vertical slope height should be measured from the pavement level up to the highest point on the rock slope from which rock fall may be expected. If rocks are coming from the natural slope above the cut, the cut height plus the additional slope height (vertical distance) should be used.

Slope height (ft)	10	20	30	40	50	60

Slope height can be measured by using different methods: 1) from images using RockSee (Figure 16), 2) manually in the field using trigonometric relationships (Figure 17), 3) by using a combination sighting level/rangefinder (Figure 18), or, 4) field estimation.

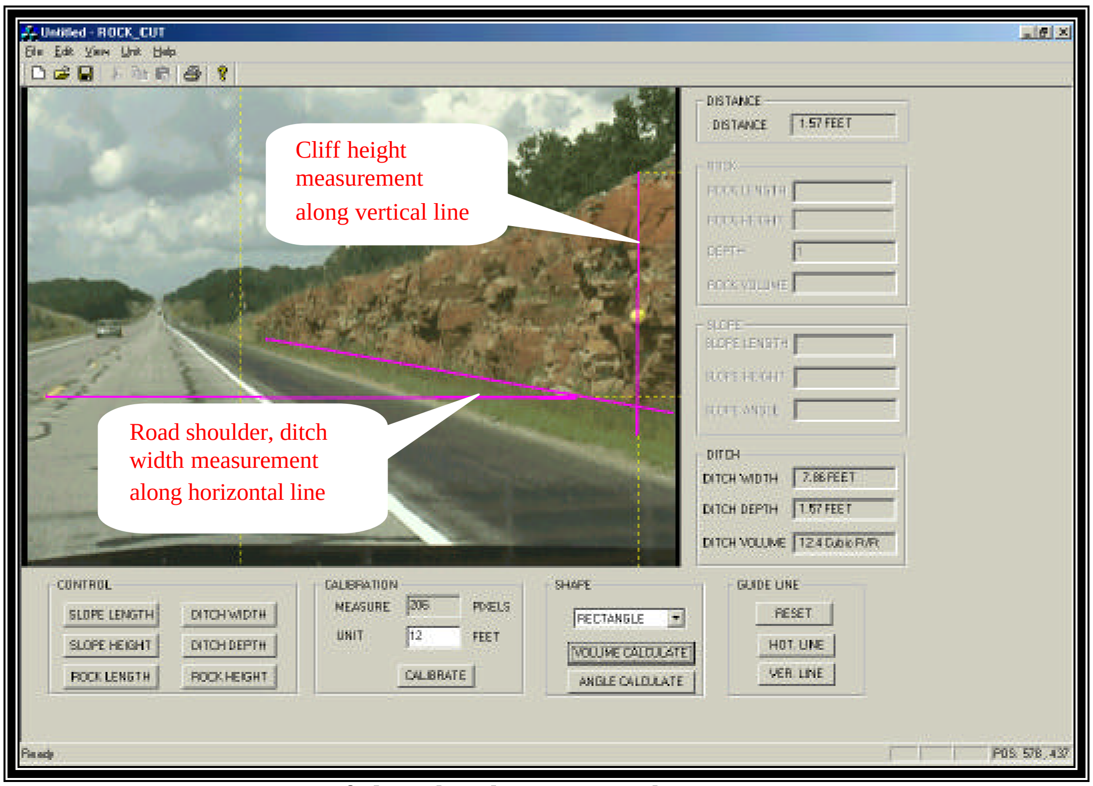


Figure 22: Measurement of slope height using RockSee.

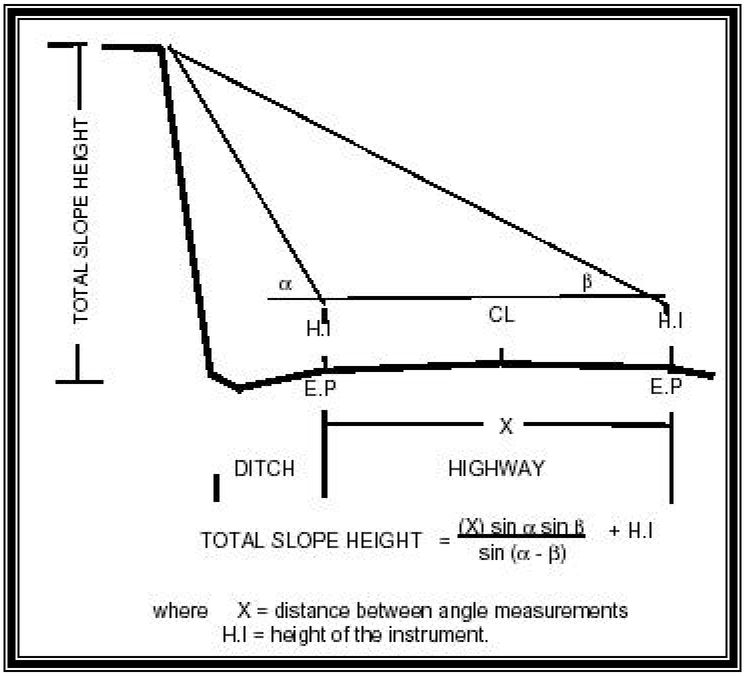


Figure 23: Measurement of slope height using this design diagram.

Figure 24: Measurement of slope height using combination sighting level, rangefinder.

Because of the nature of the rock cut heights in Missouri, it is assumed the maximum height for the system will be 60 ft and any height above 60 ft will get the highest rating.

Figure 19 shows examples of rock cuts in Missouri.

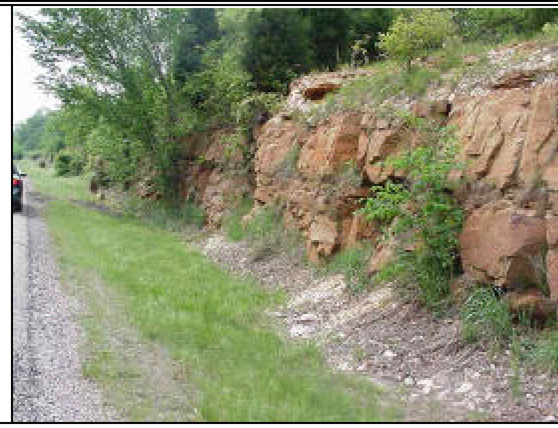
	
Height is 40 ft	Height is 8 ft

Figure 25: Examples of different rock cut heights.

5.1.5.2 Slope angle (SA)

Description and significance

The slope angle is the angle between the horizontal plane and the mean plane of the rock face/slope. The slope angle is important because the risk of failure is greater as the slope angle is increased.

Slope angle	30^o	40^o	50^o	60^o	70^o	80^o	90^o

On the other hand the slope angle for the consequence part is different because vertical cuts tend to be high risk and low consequence, while for example, slope angles of about 35° angle cuts tend to be low risk and high consequence (because of rolling and bouncing rocks). The consequence will be the highest if the slope is 30° for large blocks (because the energy and trajectory of these blocks cause them to roll to the road). For the small blocks, 85^o angles are high consequence, because the bouncing of these blocks cause them to reach the highway (CRSP analysis). For vertical slopes the consequence effect is not typically large, as the blocks may not reach the highway, falling into and being contained by the ditch

Slope angle	20^o	30^o	40^o	50^o	60^o	70^o	80^o	85^o	90^o

Slope angle can be measured by using different methods: 1) manually by using an inclinometer or Brunton pocket transit (measuring several time and averaging) (Figure 26), 2) Using the RockSee program (Figure 27), or, 3) manual estimation.

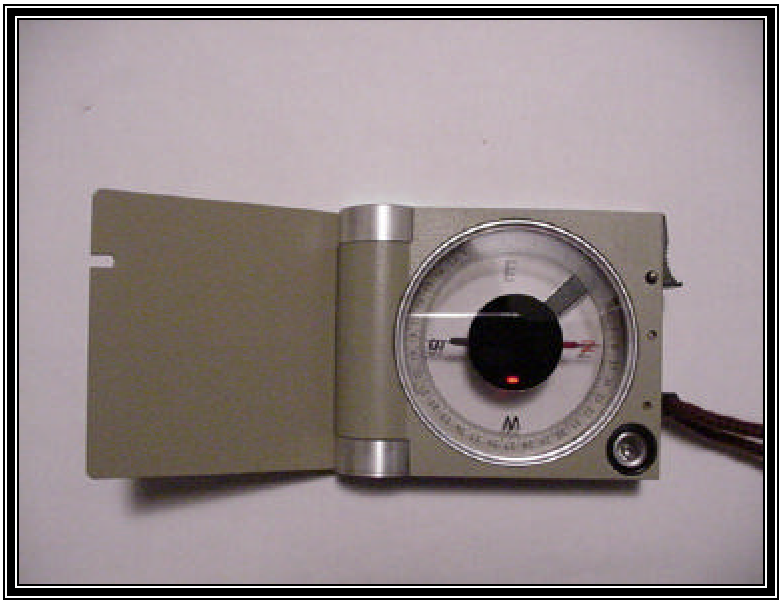


Figure 26: Inclinometer used for measuring the slope angle.

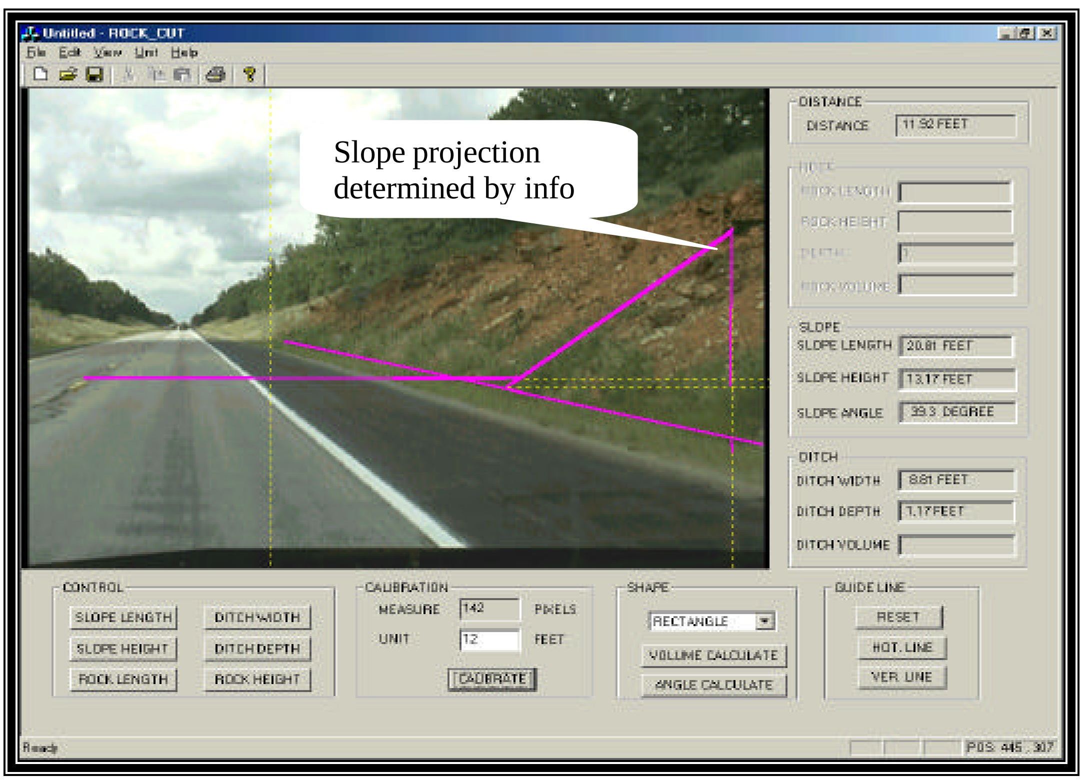


Figure 27: Measurement of slope angle using RockSee.

Figure 28 shows examples of rock slopes in Missouri.

Slope angle 90°

Slope angle 80°

Slope angle 75°

Slope angle 65°

Figure 28: Examples of rock cut slopes of different angles.

5.1.5.3 Rock Face instability (RFI)

Description and significance

This parameter summarizes a critical combination of factors leading to instability of the rock cut. Some of these factors are from the observations of previous failures. Other factors are found by looking to the ditch and face of the rock cut. It is possible to deduce that instability might occur again according to the field observations. Field observation to determine the rock fall instability and if any future rock fall events will occur or not.

RFI	Completely unstable	Unstable	Partially stable	Stable	Completely stable

Historical information is best obtained from maintenance records and accident reports, interview with maintenance personnel, on-site evidence (blocks in the ditch), and from interviews with the local populace. There may be no history available at newly constructed sites or where poor documentation practices have been followed. If this is the case, then an estimate of the instability based on the condition of the rock fall section will be made. Moreover, even the evidence of the presence of small quantities of blocks in the ditch or block plucked from the face may be useful to understand the instability factor.

Examples of rock fall instability are shown in Figure 29.

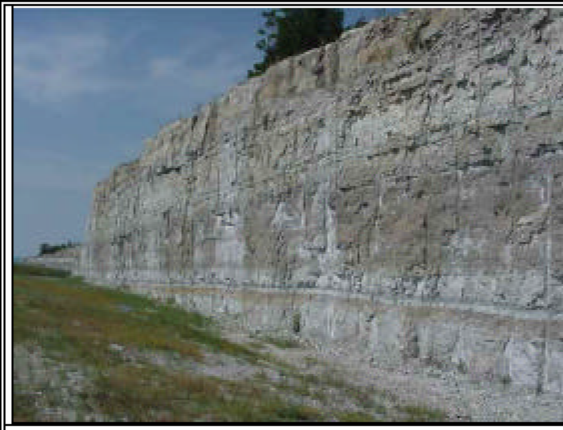
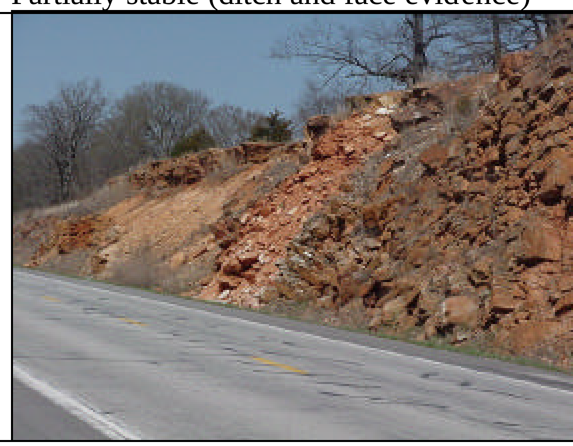
	
Completely stable	Partially stable (ditch and face evidence)
	
Unstable face (face evidence)	C. unstable (Face and ditch evidence)

Figure 29: Examples of different degrees of rock fall instability.

5.1.5.4 Weathering factor (WF)

Description and significance

The slope materials can have different properties and weathering histories that control the weathering and erosion rates.

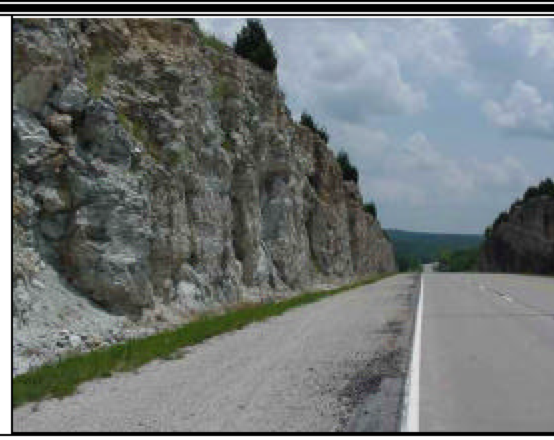
It is well known that both physical and chemical weathering increase the instability of slopes in many ways. The weathering grade is normally descriptive and the description can be converted to a rating.

Differential erosion is used for slopes where differential erosion or oversteepening is the dominant condition that leads to rock fall. Erosion features include oversteepened slopes, unsupported rock units (overhangs), or exposed resistant rocks on a slope that may eventually lead to a rock fall event. For this parameter, rock fall is commonly caused by erosion that leads to a loss of support either locally or throughout a slope. The types of slopes that may be susceptible to this condition are layered units containing more easily erodable units that undermine more durable rock talus slopes

Weathering	High	Moderate	Low	Slight	Fresh

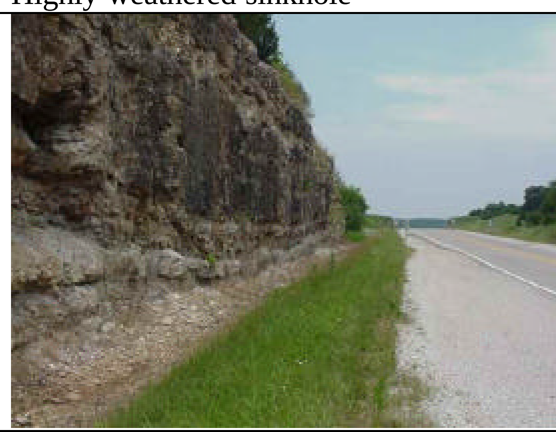
The degree of weathering is obtained from direct observation of the face of the rock cut (Figure 31)

Highly weathered face



Highly weathered sinkhole

Moderately weathered face



Slightly weathered features

Slightly weathered face	Fresh (unweathered) face

Figure 30: Examples of different weathering categories.

5.1.5.5 Strength of the intact rock (SOIR)

Description and significance

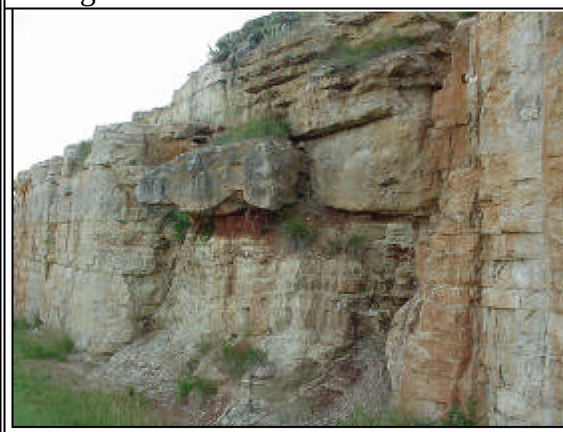
The compressive strength of the rocks on the face is a very important factor to see the durability of these materials that are on the face. Rock faces are frequently weathered near the surface by mechanical disintegration or by chemical decomposition. The weakest zone in the rock cut face is to be examined because that zone will determine the instability of the rock cut face.

Rock face strength	Very strong	Strong	Moderate	Weak	Very weak

There are many methods used to determine the strength of the weakest zone and the most popular ones are using a geological hammer and penknife. Figure 31 shows examples of rock cuts of different strengths.


Strong rock


Medium rock


Weak rock


Very weak rock

Figure 31: Examples of different rock cut face strengths.

5.1.5.6 Face irregularity (FI)

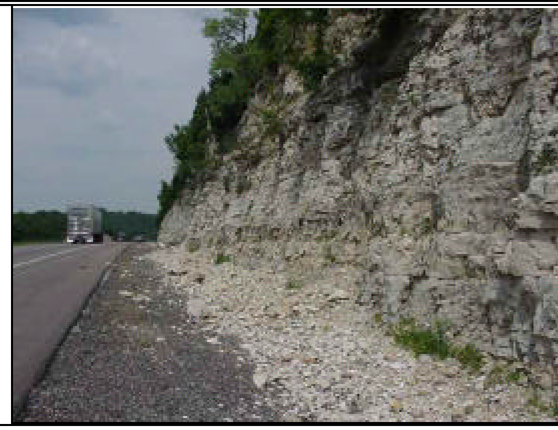
Description and significance

Face irregularity is an indicator of unstable slopes and is based on a descriptive scale. The measurement is important whether the irregularity is caused by erosion, raveling or blast over-break. If the face is very irregular that means rocks are more likely to fall down from time to time and also means this part of the rock cut is potentially unstable. Assessment is based on the following criteria: Maximum depth of overhang cut, degree of differential erosion, method of blasting, and distribution of the discontinuities and rock units. If there are many discontinuities in different directions typically the face will not be smooth and will be irregular because of blocks that have previously fallen.

Face Irregularity	Very high	High	Moderate	Slight	Smooth

Field observations are used to determine the face irregularities. Examples of different face irregularities are given in Figure 32.

Very high irregular face



High irregular face

Moderate irregular face

Slight irregular face

Smooth face

Figure 32: Examples of different face irregularities.

5.1.5.7 Face looseness (FL)

Description and significance

Face looseness is estimated based on terms of the number of open joints visible in the face, and the “looseness” of rock blocks in the face especially at the top of the cut as the top part is more hazardous than the lower part along the rock cut. This depends on the rock type, blasting history, and degree of weathering.

Face Looseness	Very high	High	Moderate	Low	No

There are two methods used to determine the face looseness, observation of looseness in the primary video survey and from on-site observation. Examples of different types of face looseness are given in Figure 33.


Very high looseness


High face looseness


Moderate face looseness


Few face looseness

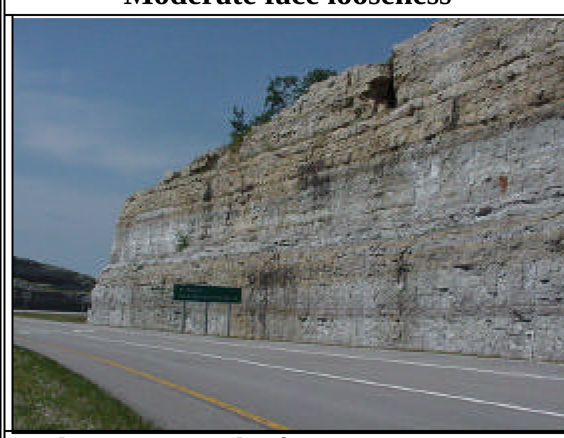

No looseness on the face

Figure 33: Examples of different degrees of face looseness.

5.1.5.8 Block size (BS)

Description and significance

As a general rule, in rock masses a small block size is inherently less stable (and has a larger risk of failure) than the larger ones. Block size as a risk factor can be determined from the distribution of discontinuities on the slope. The types of discontinuities may include joints, faults, bedding planes, and shear structures. (Rocks with numerous discontinuities are more prone to rock fall than is massive rock).

Block size however affects the consequence factor in a different way, because large moving blocks have greater kinetic energy than smaller ones, meaning they will travel further down the inclined slope and cause more damage to the road and vehicles. This factor is estimated by the maximum dimension of the largest unstable block on the slope face, or the largest block size that can be observed in the ditch. Often a more massively bedded rock slope may receive a higher rating because of the potential for larger unstable blocks.

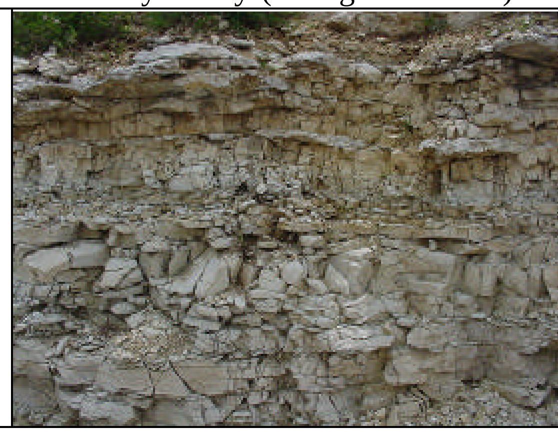
Block Size	Massive (> 5 ft)	Moderately blocky (2.5 ft)	Very blocky (1 ft)	Completely crushed (< 0.5 ft)

Block size can be determined measuring the average distance between discontinuities using a tape measure and or by using RockSee. Examples of different block sizes are given in Figure 34.

Massive average (size > 5 ft)

Moderately blocky (average size 2.5 ft)

Very blocky (average size 1 ft)



Completely crushed (average size < 0.5 ft)

Figure 34: Examples of different block sizes in rock faces

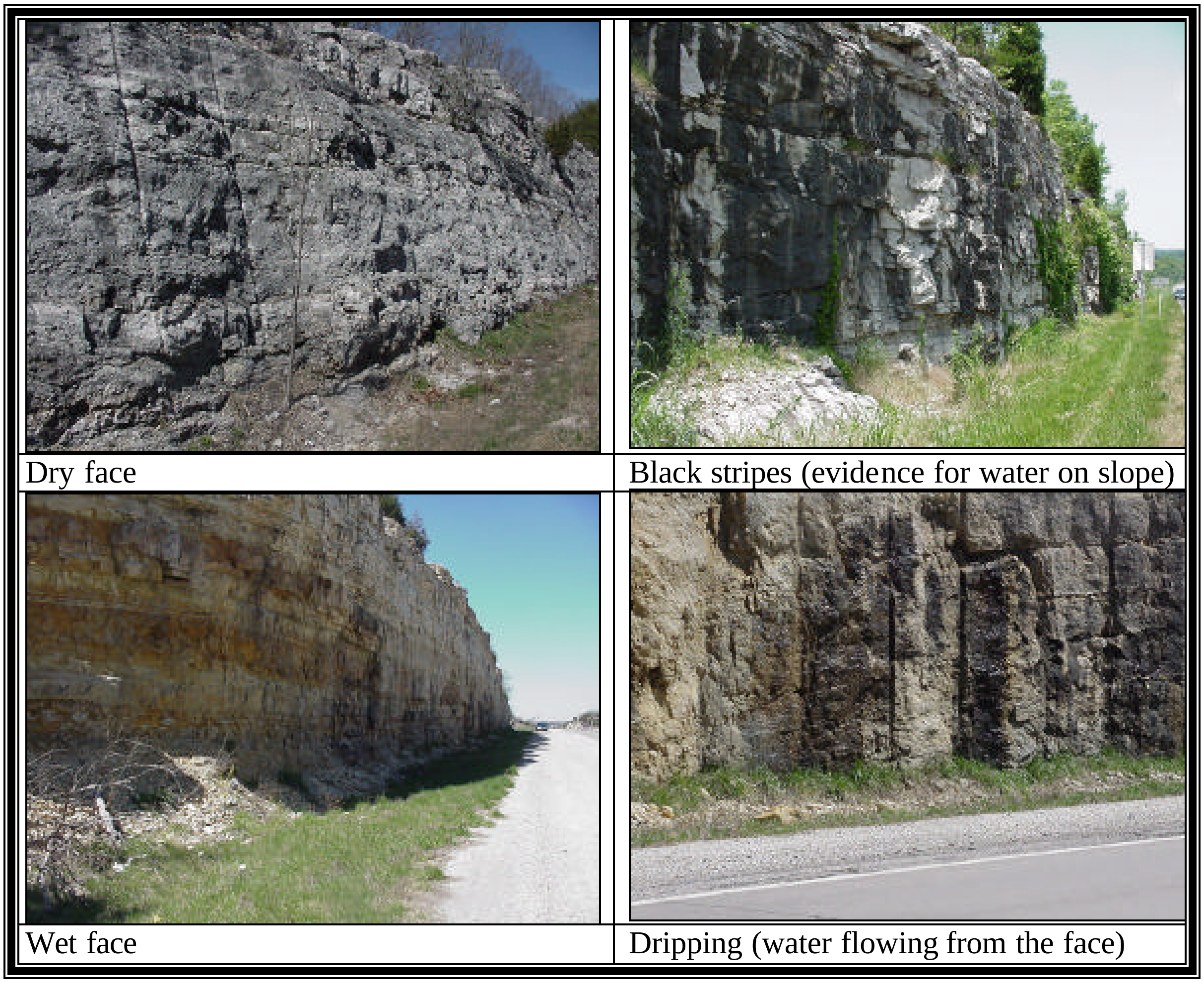
5.1.5.9 Water on Face

Description and significance

The presence of water pressures is probably the most important precursor for instability in a rock slope. Many rock falls occur after a period of particularly heavy rainfall; this period has not been unequivocally defined, although continuous heavy rainfall of 4 to 5 days is commonly critical for rock fall. After a certain period, the host rock eventually gets saturated and the local ground-water level increases. Due to increases in pore water pressure and at the same time, an increase in the weight, the slopes become prone to failure causing mass movements in the weakest directions. Sometimes, rainfall may not be the main factor but may act as the final triggering factor of the failure. Water seeping through the host rocks can lower the-cohesion and the shear strength by removing the cementing materials. Water and freeze-thaw cycles both contribute to the weathering and movement of rock materials.

Water on the Face	Dry	Damp	Wet	Dripping	Flowing

This factor is a descriptive factor and can be inferred by observing water seeping from the face (observations must be 2 to 3 days after rainfall) or by observing permanent water stains on the slope face. Examples of water on slopes are given in Figure 35.



Dry face | Black stripes (evidence for water on slope)

Wet face | Dripping (water flowing from the face)

Figure 35: Examples of different criteria as evidence for water on rock face

5.1.5.10 Ditch effectiveness (ditch width (DW), ditch shape (DS), ditch volume (SW))

Description and significance (ditch width, ditch volume)

Ditch effectiveness that we use here includes three parameters contributing to the consequence factors, which are ditch width, ditch volume and optionally ditch shape. The first two parameters estimate the consequence of ditch overspill and the probability of any rock reaching the traveled portion of the highway for vertical cuts; the last for sloped cuts and cuts with bad benches. The effectiveness of a ditch is measured by its ability to restrict rock fall from reaching the roadway. There are many factors that should be considered when designing a ditch. These factors are:

1. Slope height.
2. Slope angle.
3. Ditch width.
4. Ditch depth.
5. Ditch shape.
6. Anticipated block size and quantity of rock fall.
7. Impact of slope irregularities (features from which rocks may be launched out onto the roadway, i.e., ledges, overhangs, and protruding rock faces) on falling rocks.

Ditch effectiveness is a very important factor in the consequence analysis, where the absence of, or the presence of an inadequate ditch means that any falling rocks will reach the road and threaten vehicles. Ditch design must take into account the volume and momentum of the falling rock, so that ideally all fallen rock will be contained in the ditch.

The ditch width should be measured at the location of the highest slope height, and if the ditch width at the maximum height of the rock cut exceeds the average ditch width, the average ditch width is to be used. The ditch depth should be measured at the location of the maximum slope height from the height of the pavement edge to the bottom of the ditch.

The volume of the ditch is a very important factor from which we can see if the area in the ditch is adequate to contain most of the falling rocks without any spill out to the road. Ditch volume depends on the width and the depth of the ditch. There are two different ways to classify ditch width. If the Rock cut is vertical the following categories for ditch width are used:

Ditch width (ft)	0	5	10	15

On the other hand, if the rock cut has a bench rated as bad, or the rock cut is non-vertical the following *expanded* categories for ditch width is used.

Ditch width (ft)	0	10	20	30

The following classification is used for ditch volume, which is ditch width * average ditch depth in ft^3 per linear foot. The most important factor will affect ditch volume is the profile of the ditch depth i.e., if the cross section is triangular, rectangular, or trapezoidal.

Ditch volume (ft^3)	0	5	10	15	20	25	30

These ditch parameters can be measured by using a tape measure (Ditch width and ditch depth) (Figure36), or by using (RockSee) (Ditch width, depth, and calculate the ditch volume) (Figure 37). Examples of ditch effectiveness are given in Figure 38.

Figure 36: Manual measurements of ditch width and ditch depth.

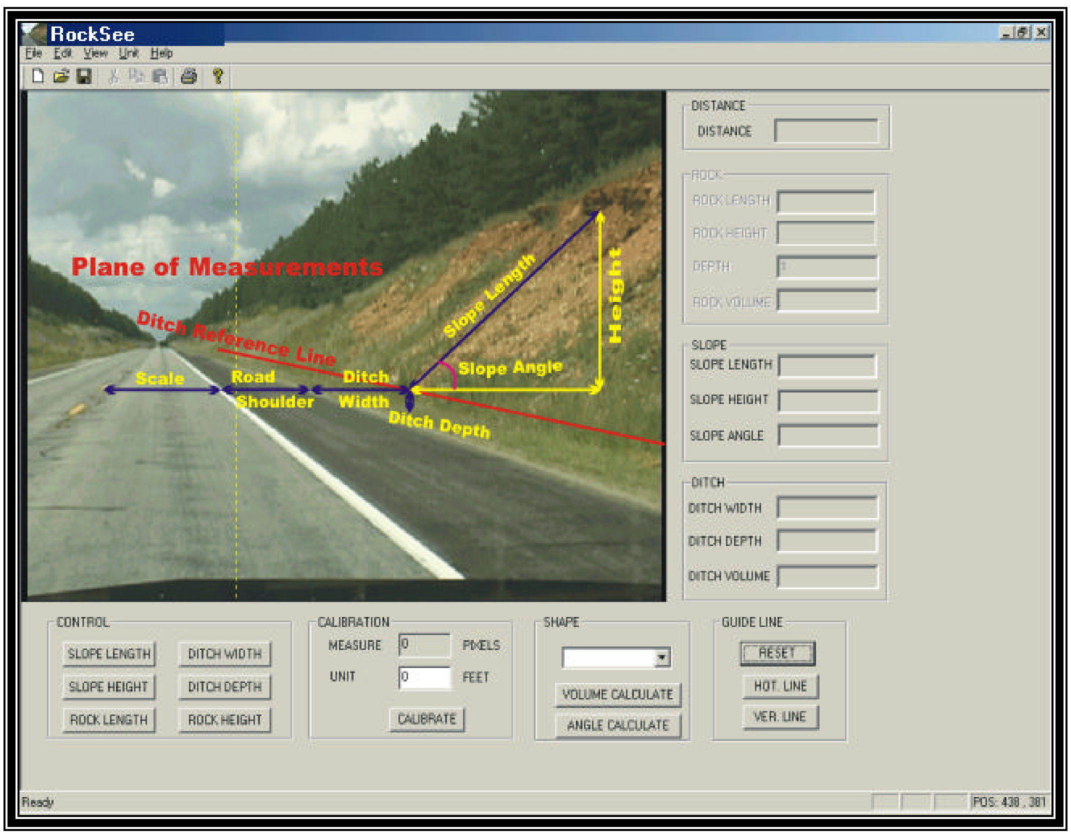


Figure 37: Using RockSee to measure ditch width and ditch width then automatically calculate the ditch volume.

Ditch effectiveness is very low (small to no ditch width and small to no ditch depth)

Ditch effectiveness is moderate (Moderately wide ditch and moderately deep ditch)

Ditch effectiveness is very good (wide ditch > 30 ft and very deep 3 ft)

Figure 38: Examples of ditches with different effectiveness.

Description and significance (ditch shape)

Ditch shape here refers to the ability of the ditch to controlling falling and rolling rocks so as not to reach the highway, in the case of non-vertical rock trajectories. If the ditch is flat or has a low back slope angle the blocks may reach the highway, but if the ditch shape has a large back slope the blocks may bounce and roll back toward the rock face. This factor is used only if a bad bench is identified or the slope angle is less than 90°.

Ditch shape	Flat 0°	Slight back slope (1V:8H) 7°	Moderate back slope (1V:6H) 9°	Large back slope (1V:4H) 14°

Ditch shape can be obtained by field estimation, or using RockSee. Examples of ditch shape are given in Figure 39.

Flat ditch

Large back slope

Figure 39: Examples of different ditch shape criteria.

5.1.5.11 Expected rock fall Quantities (ERFQ)

Description and significance

This factor estimates the maximum anticipated volume of the rocks that will fall down from the face at the failure time, including from multiple failures. This factor depends on the instability of the rock cut face, discontinuities on the face and discontinuity orientations (favorable or unfavorable), presence and size of sinkholes, and height of the rock cut.

Expected rock fall quantity is determined by measuring the area of the face, that is unstable and estimating the depth of loose zone (this depth possibly determined on the basis of face looseness and depth of overhang). Typically, if there is a filled sinkhole with loose material, the depth of material will be so large so we always give a rating of 12 for the rock fall quantity. Similarly if there are adversely oriented discontinuities on the face.

Expected rock fall quantity can be determined by field estimating the area of the hazard face and estimating a depth for the loose materials or by using RockSee to measure areas and depths where overhangs can be measured. Examples of expected rock fall quantities can be seen in Figure 40.

	
The expected rock fall quantity 15 cu ft/ft	The expected rock fall quantity >40 cu ft/ft
	
The expected rock fall quantity 0 cu ft/ft	

Figure 40: Examples of different expected rock fall quantities.

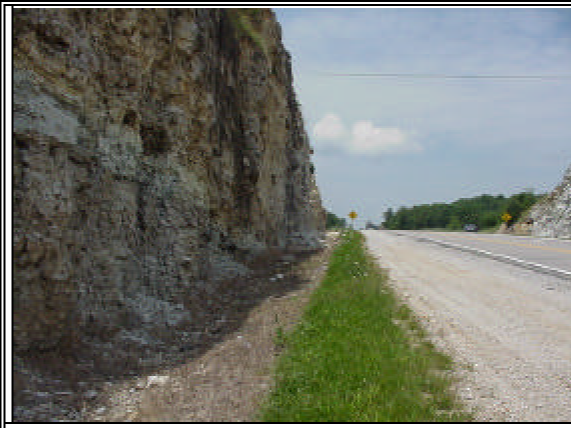
5.1.5.12 Shoulder width (SW)

Description and significance

Available shoulder width is the width of shoulder (paved or unpaved) that is available to accommodate fallen rock if the ditch area is filled to capacity. If the width is small the chance of fallen rocks reaching the highway will be high.

Shoulder (ft)	0	3	6	9	12

Shoulder width can be measured by using a tape measure in the field or by using RockSee. Examples of shoulder widths are given in Figure 41.



Shoulder width 16 ft

Shoulder width 12 ft

Shoulder width 7 ft

Shoulder width 6 ft

Figure 41: Examples of different shoulder widths.

5.1.5.13 Number of lanes (NOL)

Description and significance

The number of lanes affects the consequence values in this system. If the highway has only one lane, then the ability for the driver to avoid fallen rocks is very low. On the other hand if there are more lanes the driver has a better opportunity to avoid the fallen rocks by swerving to an adjacent lane.

Number of lanes	One lane	Two lanes	Three lanes	Four lanes

The number of lanes can be determined from field observation, RockSee video, or data from MODOT. Examples for different lanes for the sites are given in Figure 42.

Two lane highway	One lane highway

Figure 42: Examples of highways with different numbers of lanes.

5.1.5.14 Average daily traffic (ADT)

Description and significance

Traffic densities (Vehicles/day) vary considerably according to season. In Missouri the average daily traffic is almost constant during the year. ADT statistics are available from MODOT records. This is a very important factor because it will have a high influence on the consequence of rock fall, along the hazardous areas if the AVT is very high that means the chance to have serious consequences is very high.

ADT	5000 Cars / day	10000 Cars / day	15000 Cars / day	20000 Cars / day

ADT values can be found from Missouri 2000 Traffic Volume and Commercial Vehicle Counts (MODOT). Examples of different average daily traffic along the highways are given in Figures 43 and 44)

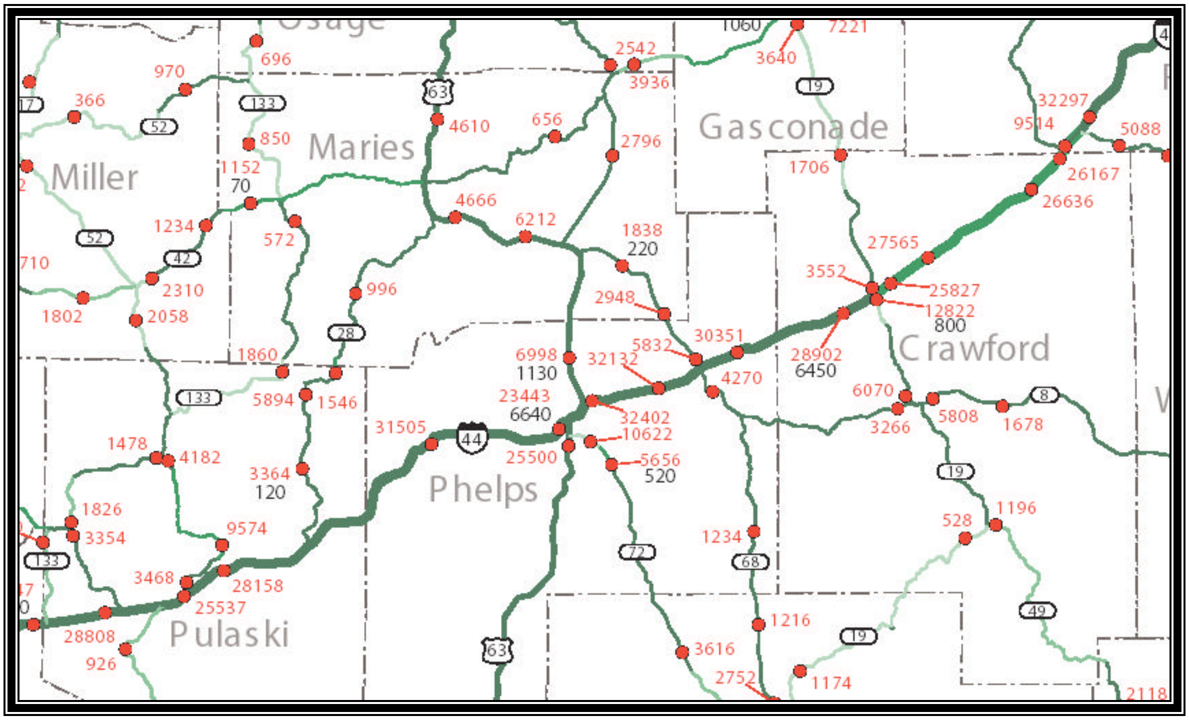
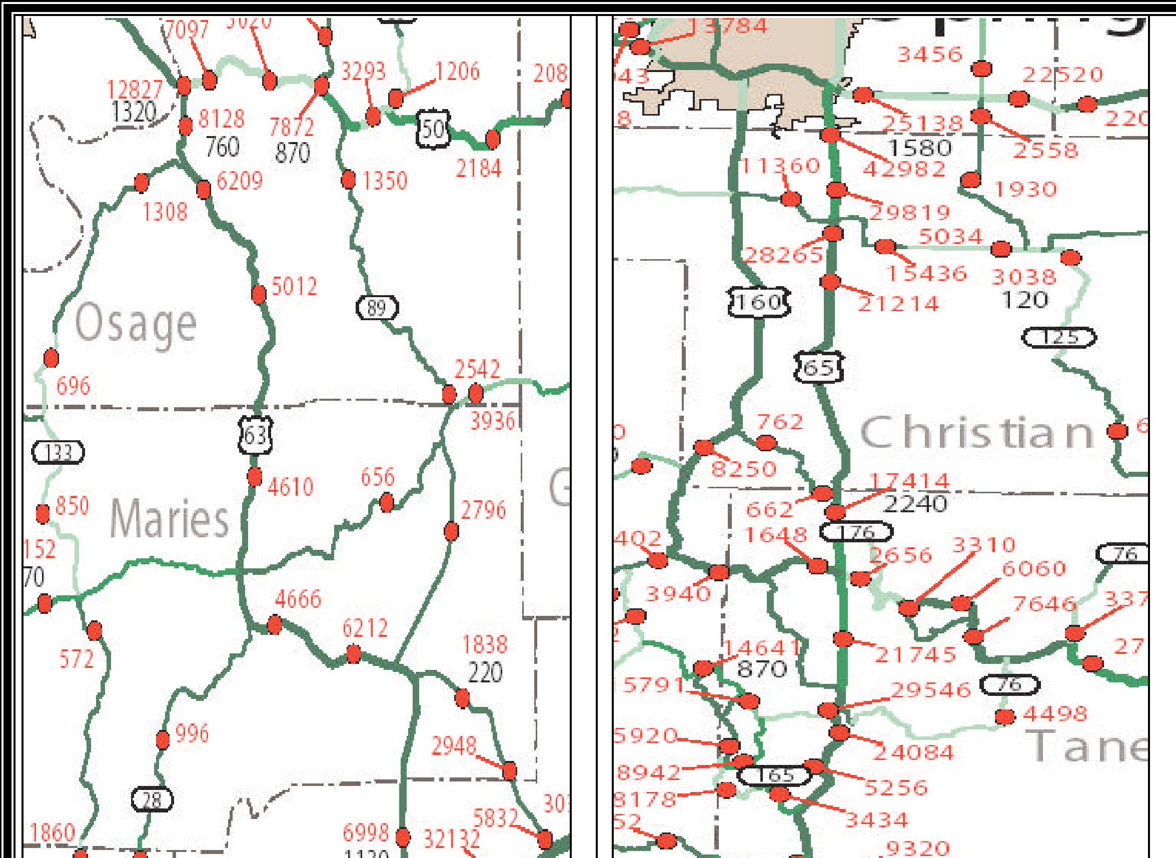


Figure 43: Part of I-44 traffic densities



Highway 63 traffic densities | Highway 65 traffic densities

Figure 44: Traffic densities along parts of highways 63 and 65.

5.1.5.15 Average vehicle risk (AVR)

Description and significance

The average vehicle risk is a measure of the number of vehicles present in the hazard zone at any given time, or, when a fractional quantity, of the percentage of time that a vehicle is present in the rock fall hazard zone. This percentage is obtained by using a formula based on slope length, average daily traffic (ADT), number of lanes, and the posted speed limit through the hazard zone:

$$AVR\% = \frac{\text{ADT (cars/day) x slope length (miles) x 100\%}}{\text{Posted speed limit (miles/hour)* number of lanes}}$$

A rating of 100% means that, at least one vehicle can be expected to be within the hazard section 100% of the time. Care should be taken to measure only the length of a slope where rock fall is a problem; overestimating lengths will strongly skew the formula results. It is possible to obtain values greater than 100% with this formula. When this happens, it means that more than one vehicle is present within the rock fall section at any one time. An AVR% score greater than 100% yields an AVR score of 100. This equation is a modified equation from the one that used by RHRS (Oregon 1993).

	Low Risk	Medium Risk	High Risk	Very high Risk
AVR	25% of the time	50% of the time	75% of the time	100% of the time

Average vehicle risk can be determined using the above equation given the number of cars per day, length of the hazard zone, posted speed limit, and number of lanes. The number of vehicles/day can be obtained from MODOT records.

The length of the hazard zone can be obtained using three different physical methods. A tape measure, measuring wheel (Figure 45), or sighting level/rangefinder (Figure 46) can be used.

Alternatively, the rock cut length can be estimated using the video log. The number of frames of video that encompass the rock cut can be counted, and if the logging vehicle has been driven with a known constant speed, then the distance (length) can be calculated with an error of less than 5% (Figures 47, 48, Table 4).

Figure 45: Measuring wheel used for measurements of rock cut length.

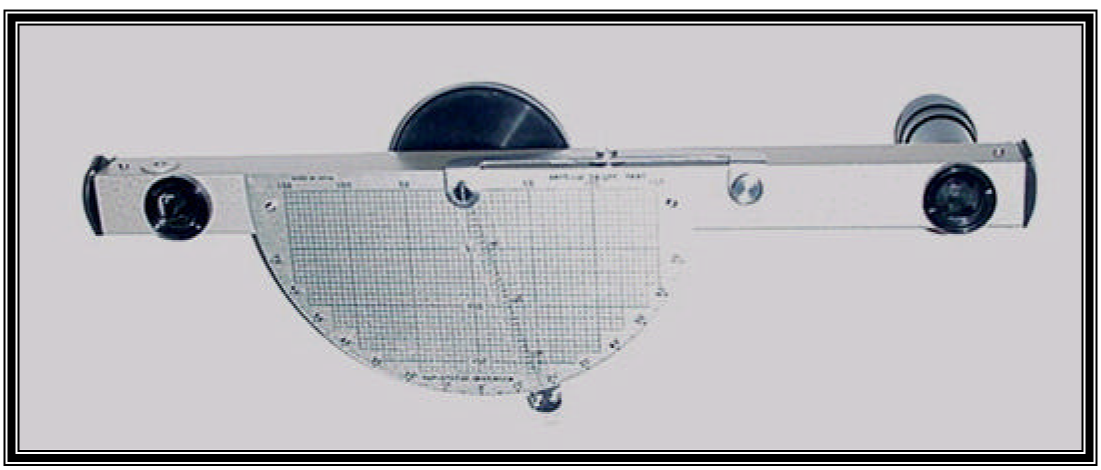


Figure 46: Sighting level/rangefinder used for measurements of rock cut length.

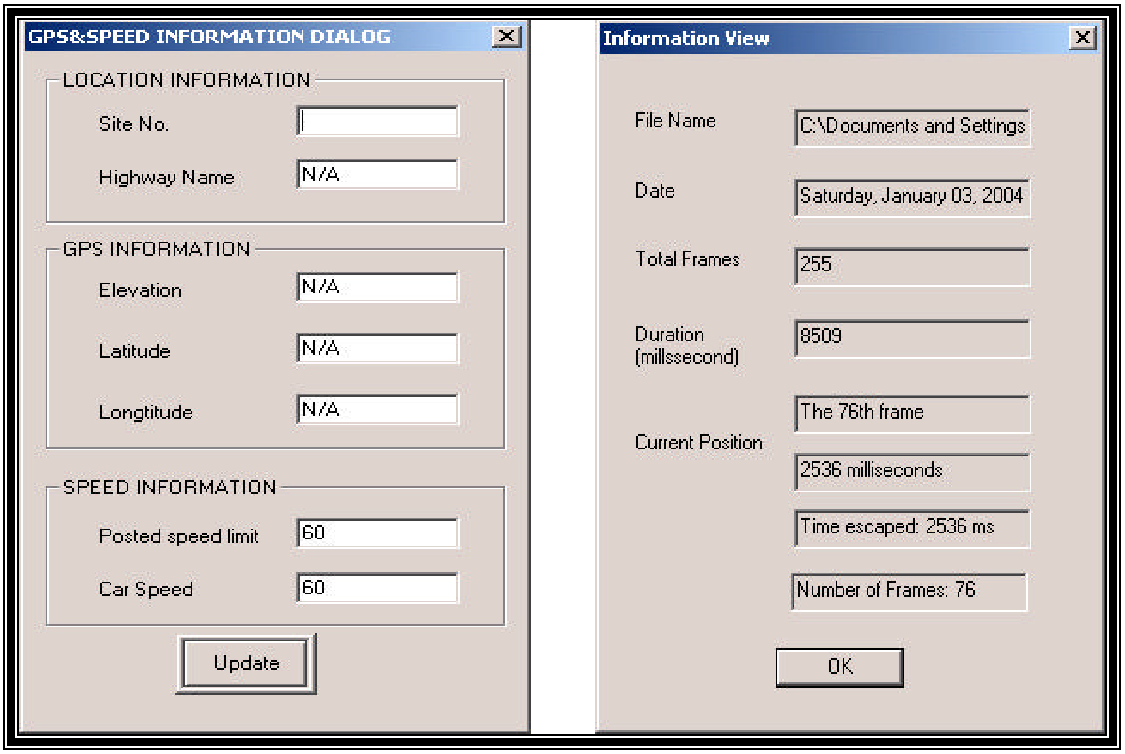


Figure 47: Determining number of frames (and consequently rock cut length) from the AVI movie.

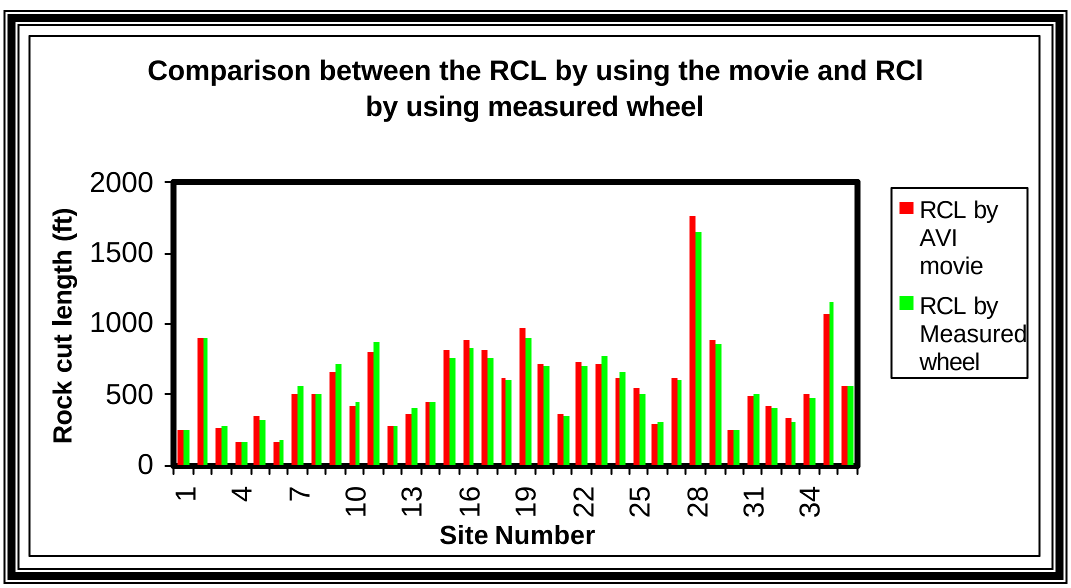


Figure 48: A comparison between RCL (rock cut length) using a computer program and measuring wheel.

Table 4: Data calculation for the rock cut length, comparison between RCL using computer and measured wheel and error %

	Speed mile/hour	Speed (ft)/sec	Frame Number	Time (sec)	No. Of frame/ sec	Frame Length ft	Length of rock cut	RCL using the wheel	Error %
1	55	80.7	93	3.03	30.69	2.63	244	250	2
2	55	80.7	338	11.07	30.53	2.64	893	900	1
3	55	80.7	111	3.21	34.58	2.33	259	270	4
4	55	80.7	67	2.06	32.52	2.48	166	160	4
5	55	80.7	148	4.27	34.66	2.33	344	320	8
6	55	80.7	65	2.04	31.86	2.53	165	170	3
7	55	80.7	202	6.21	32.53	2.48	501	560	11
8	55	80.7	206	6.26	32.91	2.45	505	500	1
9	55	80.7	251	8.11	30.95	2.61	654	720	9
10	55	80.7	169	5.19	32.56	2.48	419	450	7
11	60	88.0	276	9.06	30.46	2.89	797	870	8
12	60	88.0	105	3.15	33.33	2.64	277	270	3
13	60	88.0	139	4.19	33.17	2.65	369	400	8
14	60	88.0	163	5.13	31.77	2.77	451	440	3
15	60	88.0	291	9.21	31.60	2.79	810	750	8
16	60	88.0	301	10.01	30.07	2.93	881	830	6
17	60	88.0	296	9.26	31.97	2.75	815	750	9
18	60	88.0	211	7.01	30.10	2.92	617	600	3
19	60	88.0	376	11	34.18	2.57	968	900	8
20	60	88.0	258	8.18	31.54	2.79	720	700	3
21	60	88.0	131	4.11	31.87	2.76	362	350	3
22	60	88.0	264	8.24	32.04	2.75	725	700	4
23	60	88.0	255	8.15	31.29	2.81	717	770	7
24	60	88.0	211	7.01	30.10	2.92	617	650	5
25	60	88.0	190	6.1	31.15	2.83	537	500	7
26	60	88.0	113	3.23	34.98	2.52	284	300	5
27	60	88.0	230	7	32.86	2.68	616	600	3
28	60	88.0	656	20	32.80	2.68	1760	1650	7
29	60	88.0	339	10	33.90	2.60	880	850	4
30	55	80.7	100	3.1	32.26	2.50	250	250	0
31	55	80.7	188	6.08	30.92	2.61	490	500	2
32	55	80.7	165	5.15	32.04	2.52	415	400	4
33	55	80.7	122	4.02	30.35	2.66	324	300	8
34	55	80.7	207	6.27	33.01	2.44	506	480	5
35	55	80.7	416	13.26	31.37	2.57	1070	1150	7
36	55	80.7	211	7.01	30.10	2.68	565	550	3

The number of lanes and posted speed limit can be observed in the field or during screening of the AVI movie.

5.1.5.16 Decision sight distance (DSD)

Description and significance

The Decision Sight Distance is the distance from a hazard zone that a vehicle is when a driver is able to first recognize the hazard, either fallen rock on the highway, or falling rock on the slope. The decision sight distance (DSD) is used to determine the length of roadway in feet, a driver has to make a complex or instantaneous decision, and maneuver his vehicle to safety. Sight distance, as prescribed by the American Association of State Highway and Transportation Officials (AASHTO), is the shortest distance at which a 6-in.high object on the road is continuously visible to a driver. The decision sight distance is the length of roadway in feet, required by a driver to perceive a problem and then bring a vehicle to a stop.

Throughout a rock fall section, the sight distance can change appreciably. Horizontal and vertical highway curves, along with obstructions such as rock outcrops and roadside vegetation, can severely limit a driver's ability to see an object on the road. In this system we use a descriptive method to determine the decision sight distance.

DSD	Very Limited	Limited	Moderately Limited	Adequate

Decision sight distance is estimated in the field. Examples of different types of DSD are given in Figure 49.

DSD is very limited (vertical curve and trees)

DSD is limited (horizontal curve and trees)

DSD is moderately limited (trees)

DSD is adequate

Figure 49: Decision sight distance examples

5.1.5.17 Adversely Oriented Discontinuities (AOD)

Description and significance

This parameter is an attempt to deal with the effect of the discontinuities that have an adverse orientation toward the highway. It is related to the work has been done for the worst case of the discontinuities and factor of safety by using the computer program as (Geoplane Slide analysis V. 0.5 1992 N. H. Geo. Consulting Ltd.) and also from the data from Rock slope Engineering by Hoek and Bray (1981) describing variation of the factor of safety with the slope angle of the discontinuities).

	Favorable	Fair	Unfavorable	Very Unfavorable
Dip angle of discontinuity, dipping toward the highway	$< 20^o$	$20^o – 45^o$	$45^o - 65^o$	$65^o – 90^o$

The slope angle of the discontinuities along the face of rock cut can be measured by using an inclinometer or Brunton compass in the field. In some cases apparent dip angles can be measured using RockSee. Examples of different types of orientation of the discontinuity are given in Figure 50.

Very unfavorable discontinuity angle >65^o	Favorable discontinuity angle < 20^o

Figure 50: Examples of discontinuity orientations on the rock face

5.1.5.18 Karst effect (KE)

Description and significance

Karst features, typically filled sinkholes are very common along the Missouri highways. Understanding the filled materials from the engineering point of view will help for understand the risk and consequence effect of these karst features along the highways. Evaluation of these features will be dependent on some other factors as well:

The most important factor is the material types the fills, which could be cemented material or easy eroded materials. There are some examples along the Missouri Highways of cemented karst (sinkholes), and also a lot of karst (sinkholes) filled by materials that easy to weather and causing a problem to the highways (Figures 51, 52)

If the karst feature (sinkholes) is filled by well cemented materials the rater will deal with these as a normal cut without adding any adjustment for these features. On the other hand if the sinkholes are filled by materials that are easy to weather a karst adjustment has to be made to the rating system.

Figure 51: Sinkholes filled by cobbles and boulders of rocks surrounded by easily weathered soils (along Highway 63).

Figure 52: Sinkhole/ fractured solution filled by sandy and clayey size materials (along Highway 65).

The second factor is the extent of the karst features along the highway, the larger the feature, the greater the consequence.

The third factor that is used to understand the effect of these karst features includes evaluating the following:

1. Weathering effect on these karst materials
2. Evidence on the face and in the ditch
3. Looseness materials on the face of karst feature
4. Strength factor especially for the cement
5. Height of the sinkholes and the gradation in the size of the materials

Table 5 shows the classification of the karst and how can we deal with the problem.

Field observations are necessary to evaluate the effect of karst features along the highways. Examples of different types of karst features are shown in Figures 53 and 54.

Table 5: Karst description categories

Karst description
For the igneous, metamorphic, and not carbonate rocks
For carbonate rocks that possibly have karst features and not appear on the rock cut face or if we have a linear dissolution features
For the karst features that appear on the rock cut face and its width is 50 ft, filled by boulders and cobbles or undercut with weak materials
For the karst features that appear on the rock cut face and its width 100 ft wide, filled by boulders and cobbles with weak materials
For the karst features that appear on the rock cut face and its width 150 ft, filled by boulders and cobbles with weak materials

Sinkhole filled by fine grained materials

Sinkhole filled by boulders and weak cement

Figure 53: Classification of karst (sinkholes) according to filling materials.

Karst width > 150 ft

Karst width = 100 ft

Karst width = 50 ft

Karst width < 25 ft

Figure 54: Classification of karst according to width of the feature.

5.1.5.19 Ditch Capacity Exceedence (DCE); Ditch Capacity (Expected Rock fall Quantity/Ditch volume) (ERFQ/DV)

Description and significance

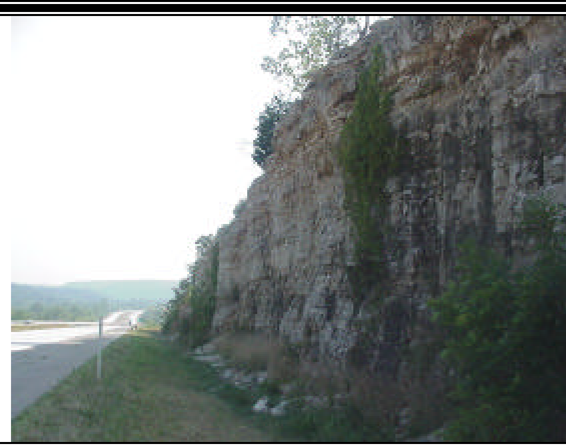
This is a very important factor that used to determine if the capacity of the ditch will be exceeded:

ERFQ/DV	1	2	3	4

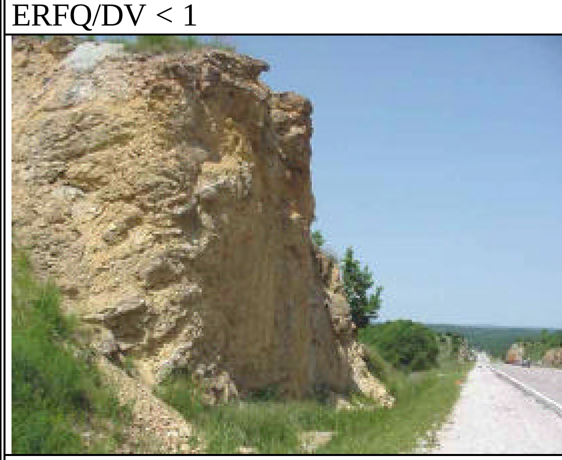
If ERFQ/DV = 1 means the ditch will retain all the falling rocks
If ERFQ/DV = 2 means the ditch will completely fill overspill somewhat
If ERFQ/DV = 3 means the falling rocks will travel at least to the shoulder of the road
If ERFQ/DV = 4 means the rocks will reach the road

The value of the ditch capacity is an internal calculation done by dividing the expected rock fall quantity by the ditch volume. Field observation a field observation is critical; however RockSee can be used to measure the ditch capacity directly. Examples of ditch capacity are shown in Figure 55.

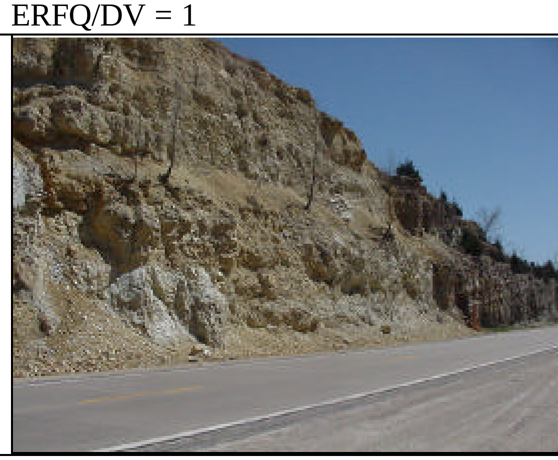
ERFQ/DV < 1



ERFQ/DV = 1



ERFQ/DV = 3



ERFQ/DV > 4

Figure 55: Ditch capacities (Expected Rock Fall Quantities/Ditch Volume)/

5.1.5.20 Bench factor (BF) and or slope factor (SF)

Description and significance

If the rock cut slope is not vertical or there are bad benches, falling rock will tend to have a horizontal trajectory. Consequently the requirements for the ditch change. The following is an algorithm to determine if the benches provide a positive or negative effect on the safety of the rock cut.

Benches

In rock cuts along highways, benches are often used to decrease the quantity of rock that falls onto the roads. Benches usually increase the level of safety from falling rock but poorly designed or maintained benches decrease the level of safety. Table 6 summarizes the approach.

Benches are beneficial (positive effect) if:

a. They are clean with no accumulated material.
b. Rock faces above the first bench are in good condition (little effect from weathering, adversely oriented discontinuities, or loose materials).
c. Benches are horizontal or they have a back slope toward the upper rock face (with lateral drainage) so the fallen blocks will be retained on the bench.
d. There are soft materials on the bench such as clay, shale, sand or gravel that will absorb the energy of the falling rock.
e. There are trees or other obstacles on the bench that will prevent the falling rocks from reaching the highway .
f. The bench is wide enough that will hold all the falling rock.

Benches are not beneficial (negative effect) if:

g. The bench slopes toward the highway; with a potential to increase the energy, velocity and horizontal trajectory of falling blocks.
h. If the upper face is highly weathered and/or undercut. This will increase the likelihood that rock blocks will overfill the bench and reach the road.
i. If the bench is not wide enough to hold the falling blocks from the all the faces above.

Table 6: Approach for good and bad benches.

	Case 1	Case 2
Condition	The bench has a positive effect	The bench has a negative effect
Rock Cut Height	The height of the first face only will be considered	Total height of the rock cut will be considered
Ditch Width Effect	The original rating for the ditch with will be used	A modified ditch width rating will be used
Slope angle effect	The slope angle of the first rock cut face will be used	The overall slope angle will be used
Ditch shape	No need to add ditch shape factor	Ditch shape factor will be used

Methods used to determine the bench effect

Field observations only are used to determine of the bench has a positive or negative effect on the highways. The following factors are used to determine this:

1. Weathering factor and differential erosion features
2. Loose material on the face
3. Irregularity factor
4. Width of the bench
5. Loose material on the bench
6. Slope of the bench

Examples of different types of bench effect are given in Figures 56 and 57.

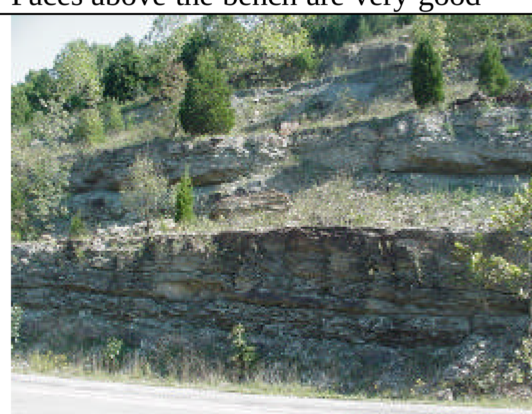
	
Bench is clean	Faces above the bench are very good
	
Good ditch and large back slope	Wide bench with soft material cover it

Figure 56: Examples of good benches.

	
Bench slopes toward the Highway	High loose materials above the bench
	
High weathering above the bench	Very narrow bench width

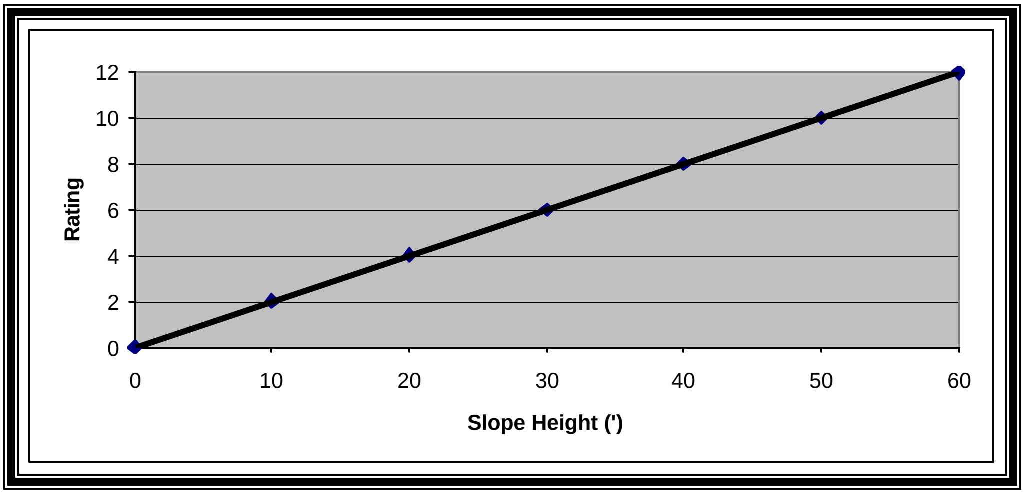
Figure 57: Examples of poor benches.

5.1.6 Rating of the risk-consequence parameters

5.1.6.1 Slope height (SH)

Rating = Slope Height * 0.2

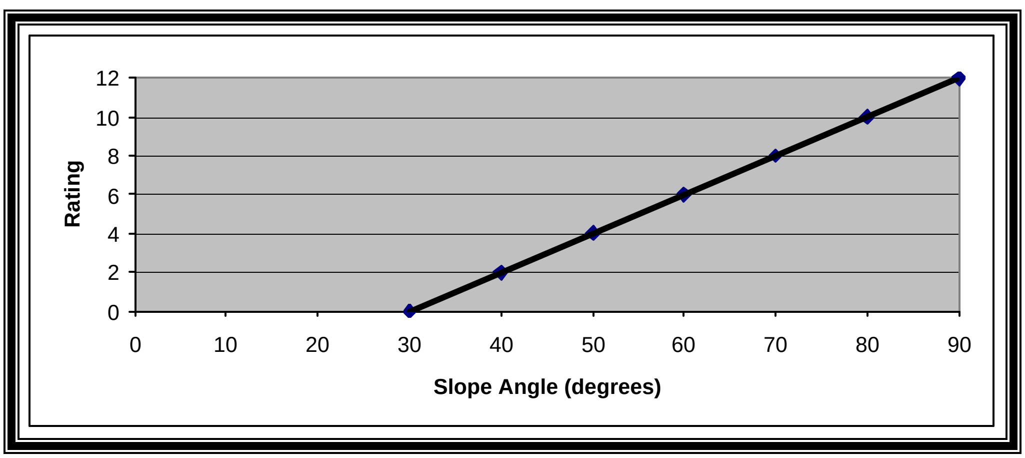
Slope height (ft)	10	20	30	40	50	60
Rating	2	4	6	8	10	12



5.1.6.2 Slope angle (SA) (risk rating)

Rating = 0.2 * slope angle – 6

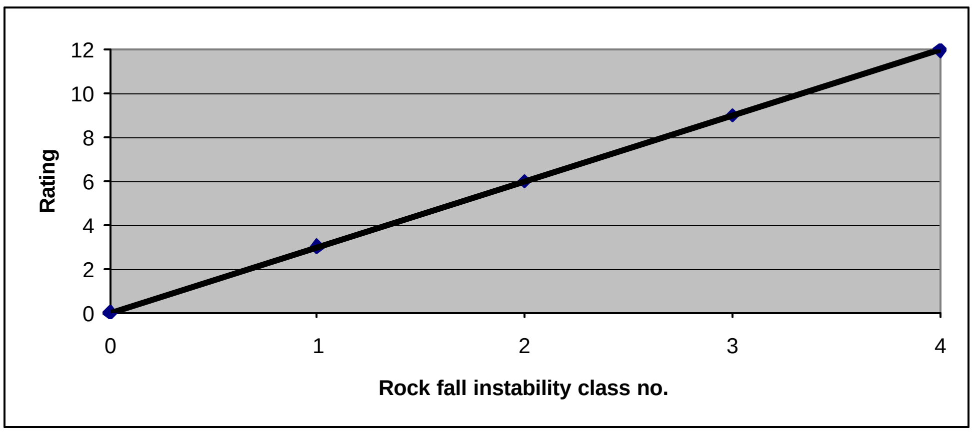
Slope angle	30^o	40^o	50^o	60^o	70^o	80^o	90^o
Rating	0	2	4	6	8	10	12



5.1.6.3 Rock fall instability (RFI)

Rating = 3 * RFH Class number

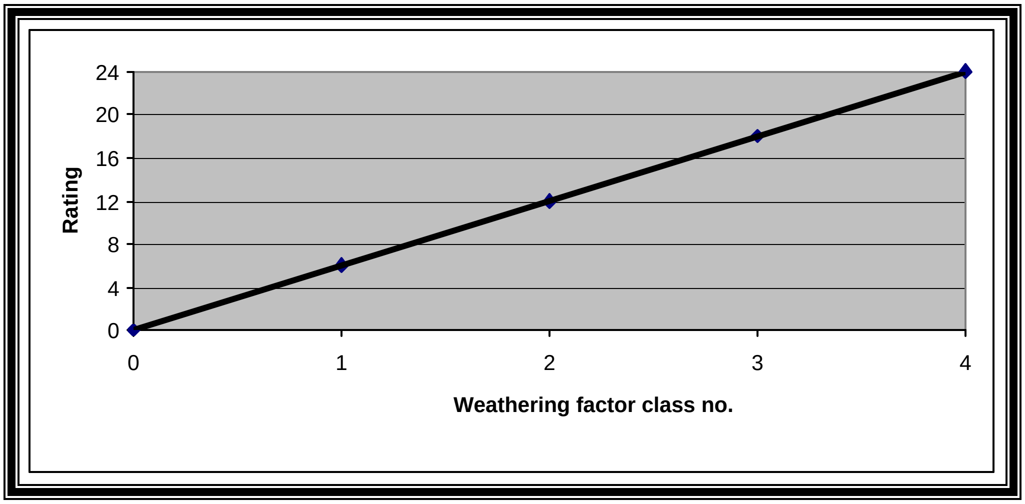
RFI	Class No.	Description	R
Completely unstable	4	Rocks often fall in this area and there is considerable evidence for that in the ditch and from maintenance records; this will be in sites where severe rock fall events are common	12
Unstable	3	Rocks fall from time to time; the rock falls will occur frequently during certain times of the year, but will not be a significant problem during other times; this also is used where significant rock falls have occurred in the past	9
Partially stable	2	Rocks fall occasionally; rock falls can be expected several times per year, usually during storms.	6
Stable	1	Very few blocks fall during a the year and only during a severe storms	3
Completely stable	0	No rock falls; no historical and physical evidence for any rock fall in the area	0



5.1.6.4 Weathering factor (WF)

Rating = 6 * WF class number

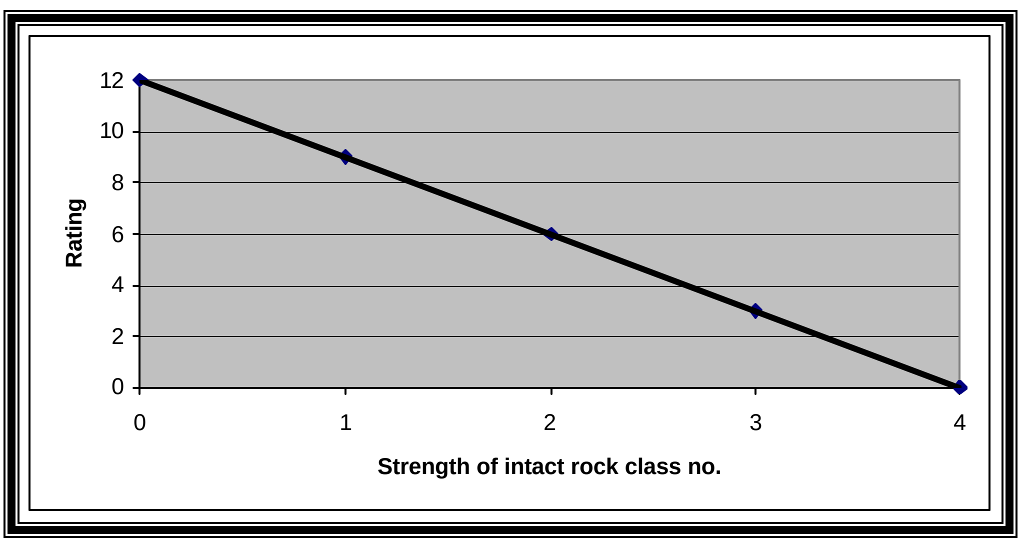
WF	Class No.	Description	R
High	4	Major erosion features are present, there are many overhanging areas along the rock cut, differential erosion is evident along the rock cut	24
Moderate	3	Some erosion features are present, differential erosion features are large and numerous throughout the rock cut	18
Low	2	Minor differential erosion features appear widely distributed throughout the area, the differential erosion rate is limited	12
Slightly	1	Few differential erosion features, and the erosion rate is very low	6
Fresh	0	No evidence for weathering and the walls are smooth and planar	0



5.1.6.5 Strength of intact rock (SOIR)

Rating = -3 * SOIR class number + 12

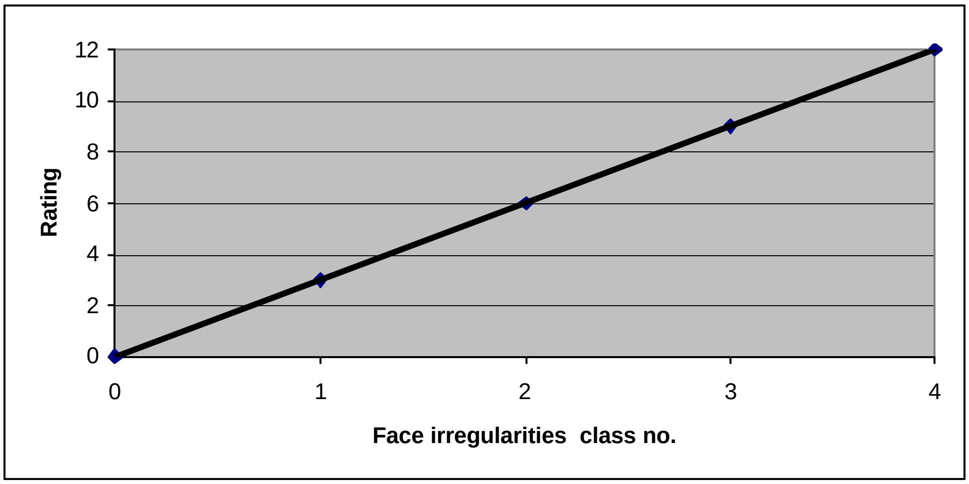
SOIR	Class No.	Description	R
Very strong rock	4	> 14504 psi, many blows by the hammer needed to fracture the rock	0
Strong rock	3	7252 – 14504 psi, several blows to fracture the rock	3
Moderately strong rock	2	3626 – 7252 psi, A firm blow needed to fracture the rock	6
Weak rock	1	725 – 3626 psi, can indent the rock with a pick	9
Very weak rock	0	145 - 725 psi, can crumble by hand	12



5.1.6.6 Face Irregularity (FI)

Rating = 3 * FI class number

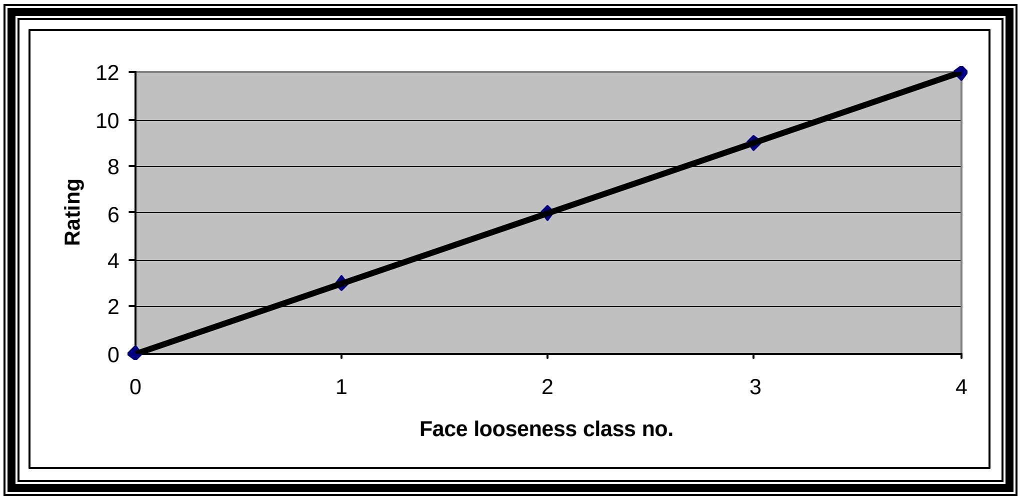
FI	Class No.	Description	R
Very high irregular face	4	There are many joints and overhanging features, irregular features everywhere throughout the site, the face is stepped everywhere	12
Highly irregular face	3	Much of the face is irregular and there are many joints and stepped faces	9
Moderately irregular face	2	There are many irregular areas in the face	6
Slightly irregular face	1	There are some irregular areas along the face	3
Smooth face	0	Very smooth face	0



5.1.6.7 Face Looseness (FL)

Rating = 3 * FL class number

FL	Class No.	Description	R
Very highly loose material	4	The face is completely covered by loose blocks	12
Highly loose material	3	Much of the face is covered by loose blocks	9
Moderately loose material	2	Some of the face is covered by loose blocks	6
Low loose material	1	Little of the face is covered by loose blocks	3
No loose material	0	There are no loose blocks on the face	0

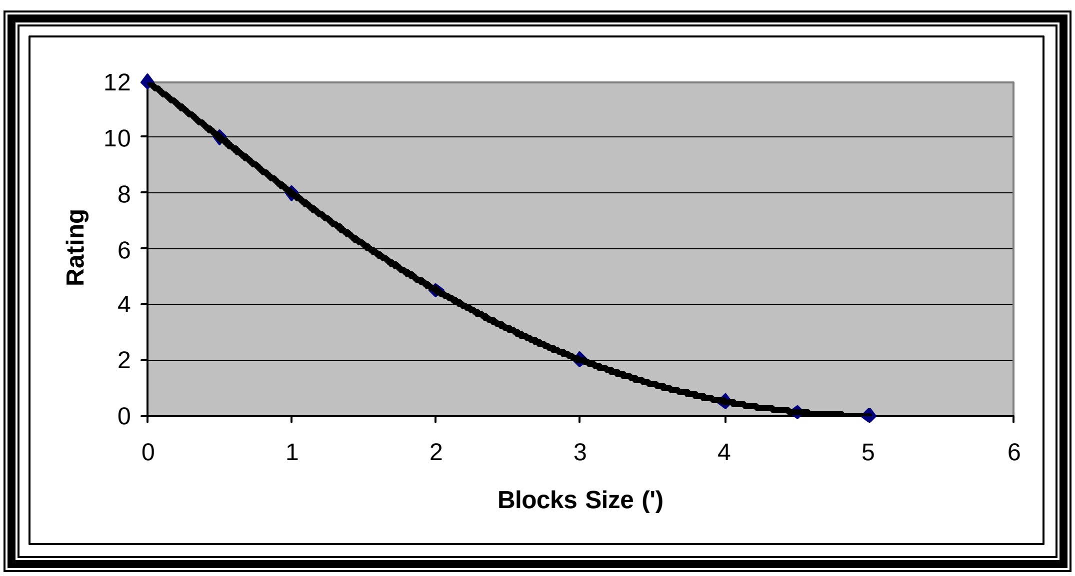


5.1.6.8 Block Size (BS) (risk rating)

Rating = -0.0004*BS^6 + 0.0096* BS^5 - 0.0894*BS^4 + 0.4136* BS^3 - 0.493*BS^2 - 3.8423*BS + 12

Where: BS is the Block Size in feet.

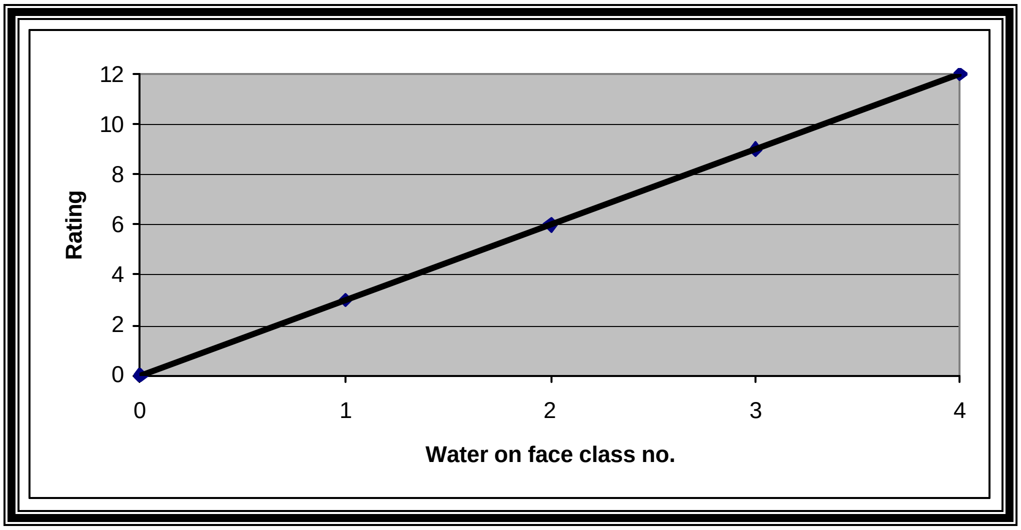
Block Size	Description	R
Massive	Blocks are large and average joint spacing 5 ft	0
Moderately blocky	Average block size is 2.5 ft	4
Very blocky	Average block size is 1 ft	8
Completely crushed	Intact rock has the character of a crushed run aggregates, joint spacing is less than 0.5 ft	12



5.1.6.8 Water On Face (WOF)

Rating = 3 * WOF class number

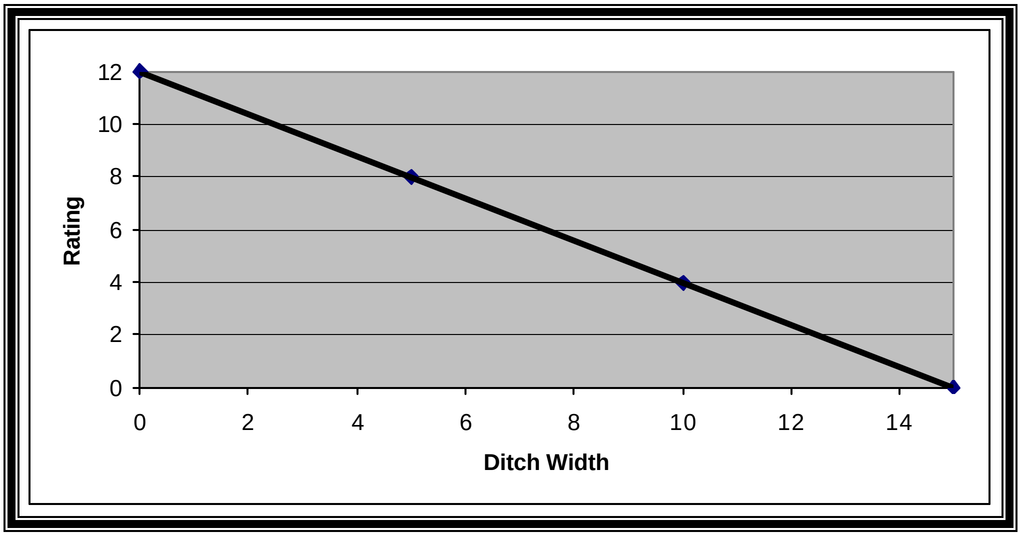
WOF	Class No.	Description	R
Dry	0	There is no water on the face	0
Damp	1	There is evidence of water on the face	3
Wet	2	There is evidence of significant water on the face	6
Dripping	3	Water drips from the face	9
Flowing	4	Water flows from the face	12



5.1.6.9 Ditch Width (DW)

Rating = - 0.8 * DW + 12

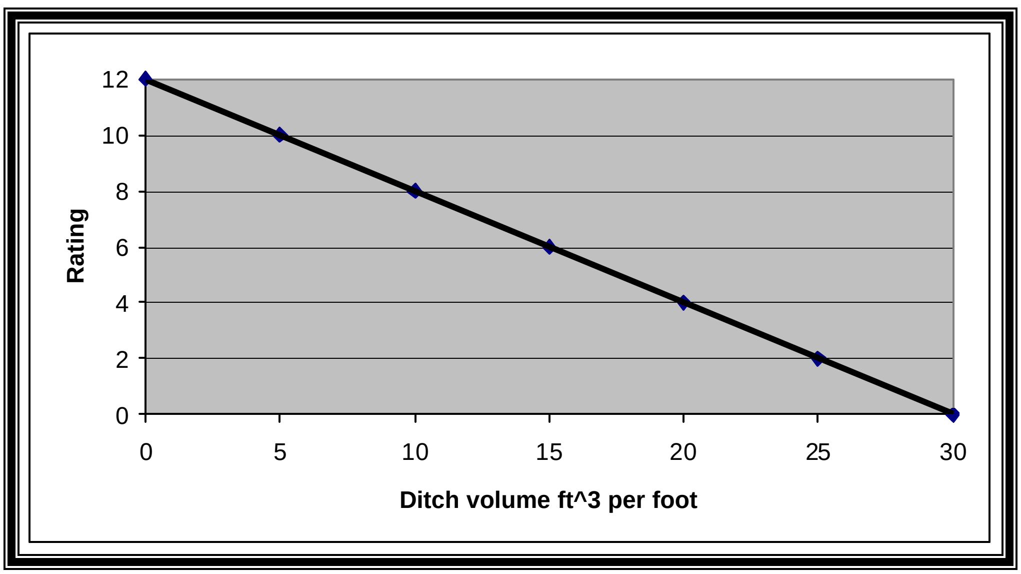
DW (ft)	0	5	10	15
Rating	12	8	4	0



5.1.6.10 Ditch Volume (DV)

$$Rating = -0.4 * DV + 12$$

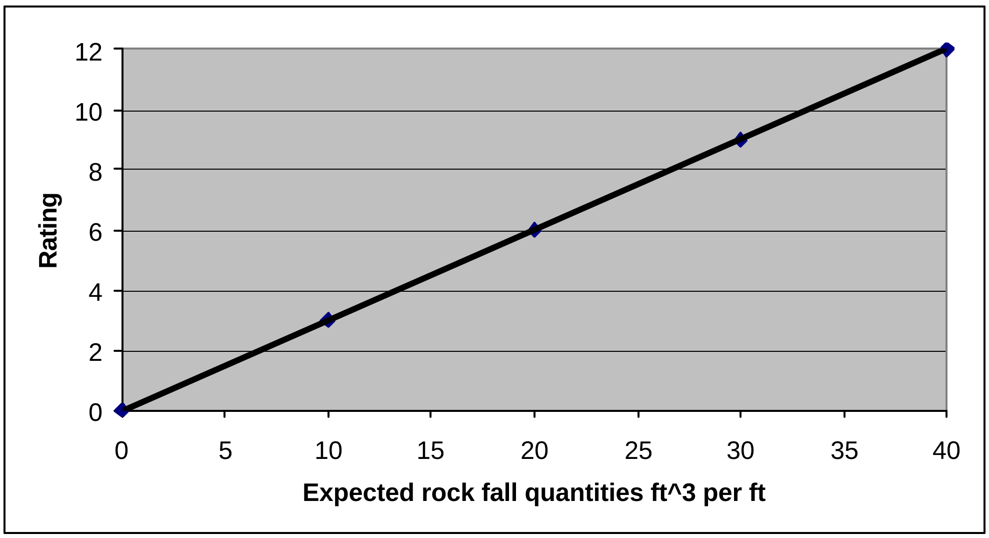
Ditch volume (ft^3)	0	5	10	15	20	25	30
Rating	12	10	8	6	4	2	0



5.1.6.11 Expected rock fall quantities (ERFQ)

Rating = 0.3 * RFQ

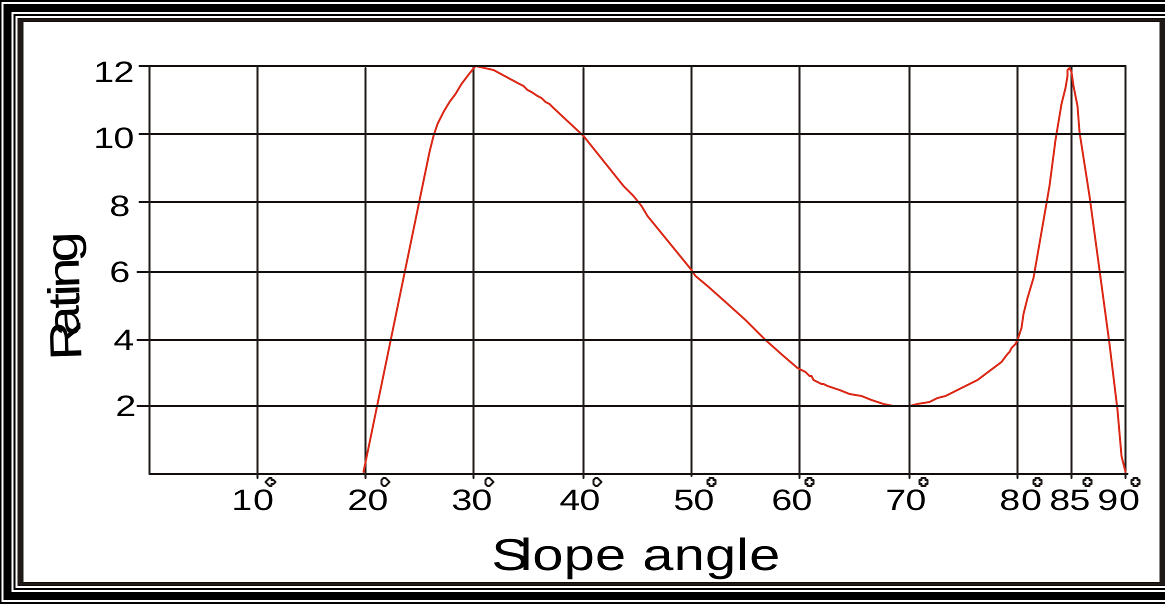
ERFQ	Description	R
> 40 cubic feet per linear foot	The face is completely loose and the expected volume of falling rocks will be about 40 cu ft/ft	12
30 cubic feet per unit foot	Most of the face is loose and the expected volume of falling rocks will be 30 cu ft/ft	9
20 cubic feet per linear foot	Many areas of the face are loose and the expected volume of falling rocks will be 20 cu ft/ft	6
10 cubic feet per linear foot	Few areas on the face are loose and the expected volume of falling rocks will be 10 cu ft/ft	3
Less than 5 cubic feet per unit linear foot	There is no expected rock fall (there is no loose materials on the face)	0



5.1.6.12 Slope angle (SA) (consequence rating)

For slope angle from 20 – 30°	Rating = 1.1913 * SA – 23.682
For slope angle from 30 – 70°	Rating = -0.2569* SA + 19.55
For slope angle from 70 – 85°	Rating = 07095* SA –48.453
For slope angle from 85 – 90°	Rating = -2.4 * SA + 216

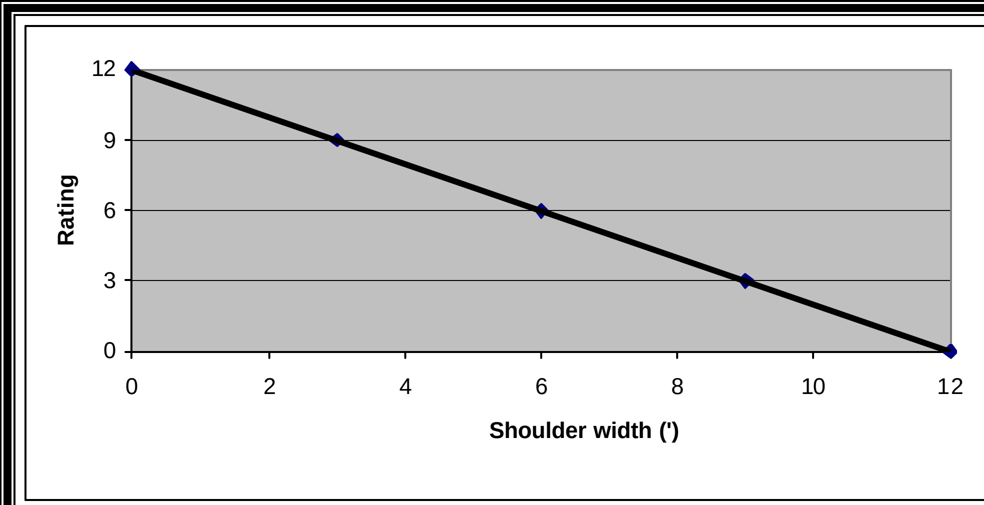
Slope angle	20°	30°	40°	50°	60°	70°	80°	85°	90°
Rating	0	12	10	6	3	2	4	12	0



5.1.6.13 Shoulder width (SW)

Rating = - SW +12

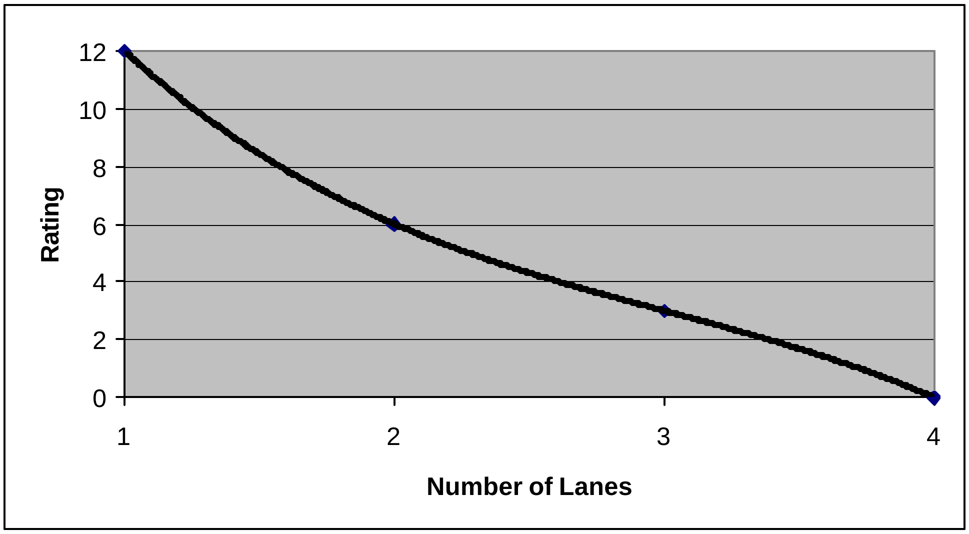
Shoulder (ft)	0	3	6	9	12
Rating	12	9	6	3	0



5.1.6.14 Number of lanes (NOL)

Rating = -0.5* (NOL)^3 + 4.5* (NOL)^2-16*(NOL)+24

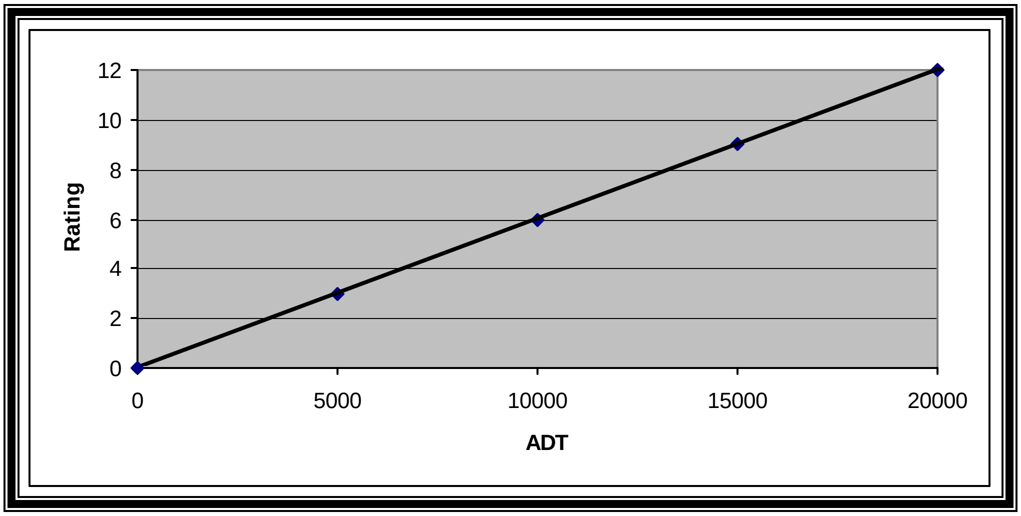
NOL	One lane	Two lanes	Three lanes	Four lanes
Rating	12	6	3	0



5.1.6.15 Average daily traffic (ADT)

Rating = 0.0006 * ADT

ADT	5000 Cars / day	10000 Cars / day	15000 Cars / day	20000 Cars / day
Rating	3	6	9	12



5.1.6.16 Average vehicle risk (AVR)

AVR % = (NOV/day/lane) * (RCL ft) *(0.000189394) / (PSL m/hr)* 24

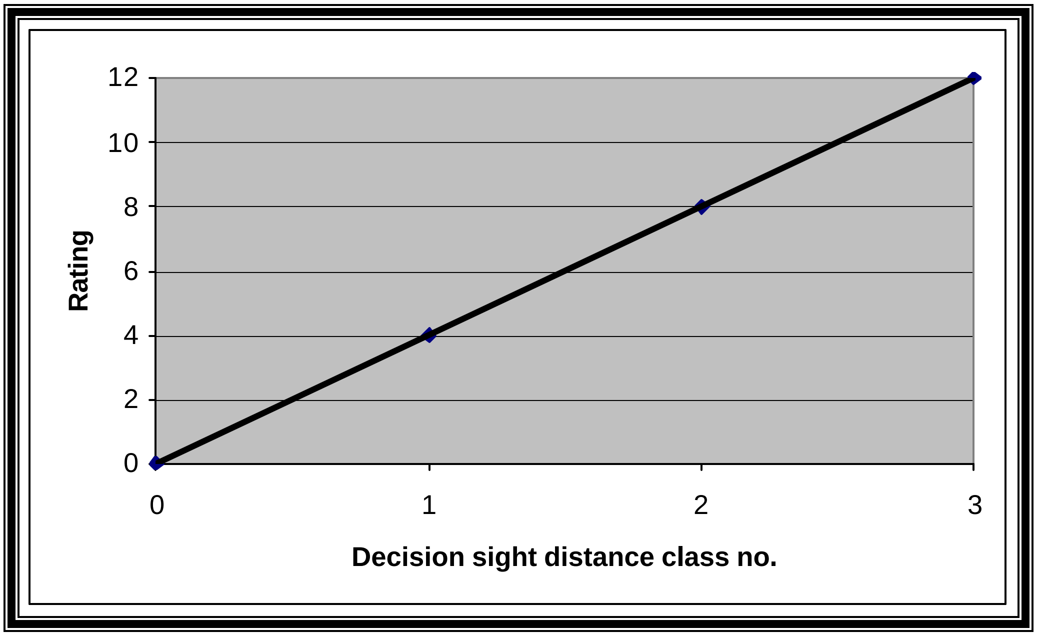
Where: NOV number of vehicles per day and per lane,
RCL Rock cut length (hazard zone)
PSL Posted Speed Limit

AVR	Description	R
Low Risk	25% of the time the vehicle will be in the rock cut zone	3
Medium Risk	50% of the time the vehicle will be in the rock cut zone	6
High Risk	75% of the time the vehicle will be in the rock cut zone	9
V. High Risk	100% of the time the vehicle will be in the rock cut zone	12

5.1.6.17Decision Sight Distance (DSD)

Rating = 4 * DSD class number

DSD	Class No.	Description	R
Very limited	3	Distance is very small and there are many vertical and horizontal curves on the roads, vegetation obscures falling rock	12
Limited	2	There are some curves and obstacles on the road not giving the driver enough time to perceive that there are falling rocks on the road	8
Moderate	1	There are few curves and obstacles and the driver can control the vehicle easily because he sees falling or fallen rocks	4
Adequate	0	The road is completely straight with out any obstacles or curves and the driver can see the entire rock face and road at any time	0

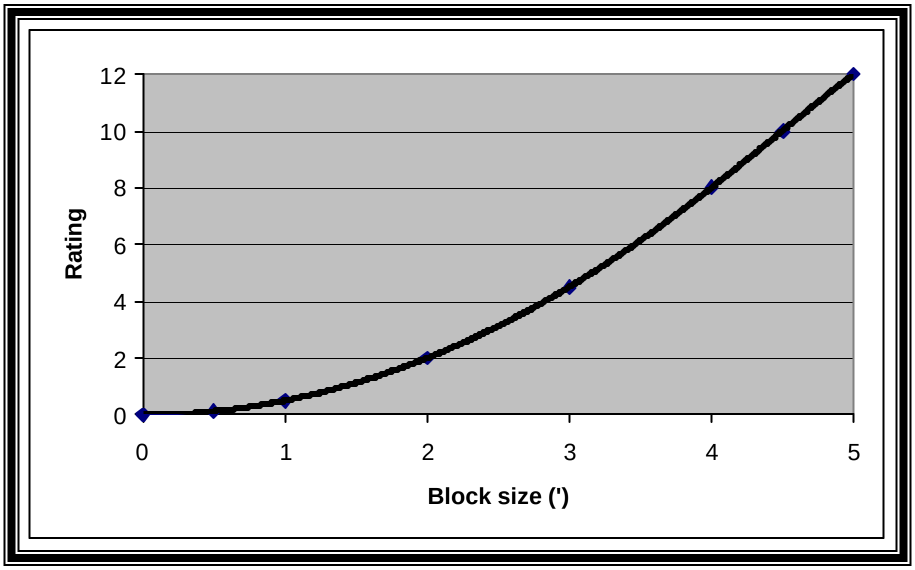


5.1.6.18 Block Size (BS) (consequence rating)

Rating = -0.0004*BS^6 + 0.0023* BS^5 + 0.0011*BS^4-0.0267* BS^3 + 0.5464*BS^2 - 0.0208*BS + 0.14

Where: BS is the Block size in feet.

BS	Description	R
Massive	Blocks are large and average joint spacing 5 ft	12
Moderately blocky	Average block size is 2.5 ft	8
Very blocky	Average block size is 1 ft	4
Completely crushed	Intact rock has the character of a crushed run aggregates, joint spacing is less than 0.5 ft	0



5.1.6.19 Adversely oriented discontinuities (AOD)

Rating value = 4 * class number

	Favorable	Fair	Unfavorable	Very Unfavorable
Class No.	0	1	2	3
Dip angle of discontinuity	< 20	20 – 45	45 - 65	65 – 90
Rating	0	4	8	12

5.1.6.20 Karst factor

Rating value = 4 * class number

Filled sinkhole description	Class number	Rating
No sinkhole, or sinkholes filled by cemented materials, or Sinkholes filled by very loose materials like sand and clay	0	0
Small 50 ft wide filled by boulders and cobbles or undercut with weak materials	1	4
Medium 100 ft wide filled by boulders and cobbles with weak materials	2	8
Large 150 ft wide filled by boulders and cobbles with weak materials	3	12

5.1.6.21 Ditch Capacity (Expected Rock fall Quantity/Ditch volume) (ERFQ/DV)

Rating value = 5 * Adjustment value - 5

ERFQ/DV	1	2	3	4
Rating Value	0	5	10	15

5.1.7 Derivation of the risk-consequence parameter ratings

Many rock fall hazard rating systems are in North America, the most popular one is the Rockfall Hazard Rating System developed by the Oregon Department Of Transportation (ODOT) (Pierson and Vickle, 1993). Another one is the Rockfall Hazard Rating system Ontario (Franklin and Senior, 1987a). These systems are very useful tool to evaluate rock slope for potential instability due to rock falls.

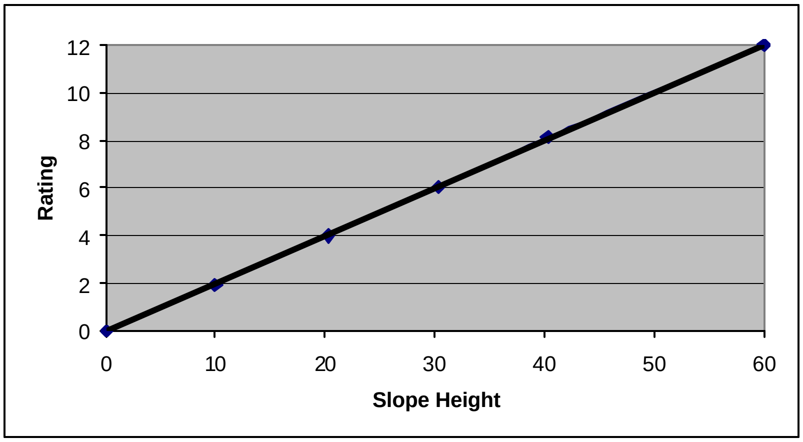
In MORFH RS we use both these systems as a base for developing this system with some changes due to the following factors in concerned.

1. Separation of Risk Parameters from Consequence parameters that is allowed us to see potential of the rocks to fall which we called risk of failure and the potential of these falling rocks to reach the highways and damage both vehicles and highways which called consequence of failure.
2. Adding, removing and modifying some factors due to the geological environment in the Missouri State, also to make the system more simple and effective in use
3. Using Video Log for screening and measuring most of the factor of the rock cuts, this will save much money in which we will look at the rock cuts from the video image and determine which one need detail analysis.

In the following part we will discuss the factors that we modified and added to the MORFH RS to deal with the all situation in Missouri rock cuts.

5*.1.7.1 Slope height (SH)*

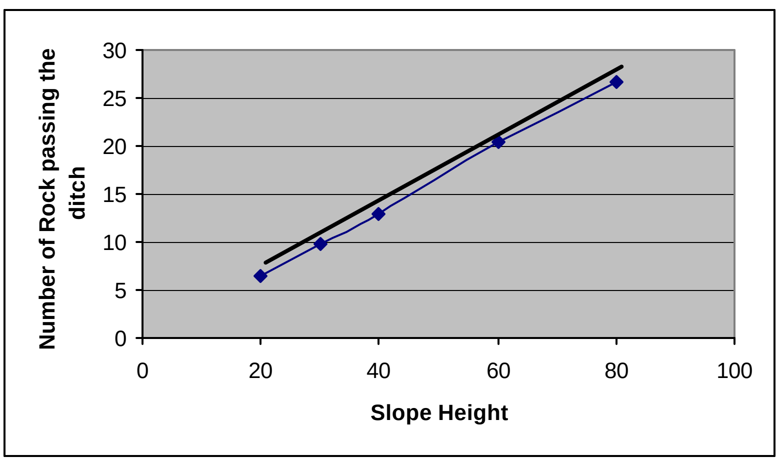
As a rule, the higher the slope height, the greater is the risk of failure. A linear approach was adapted, where slopes were rated between 0 and 12, for heights of 0 to 60'. Slopes above 60' are rated at the maximum "12" value.



Although not on the risk side, the Colorado Rockfall Simulation Program (CRSP) was used to evaluate the effect of slope height on a fixed angle cut, in terms of the number of rocks passing out of the ditch. The following is one example of these tests:

Slope angle = 40°

Rock passing the ditch	6.4	9.8	13	20.4	26.6
Slope Height	20	30	40	60	80



From this relationship it can be argued that a linear relationship between height and rating may be appropriate

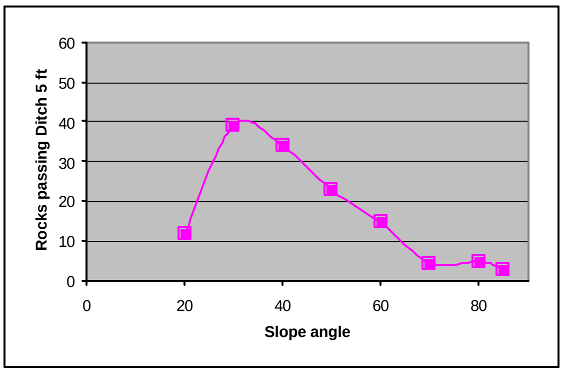
5.*1.7.2 Slope angle (SA) (Consequence)*

For this analysis, the CRSP program was used as well. Choosing constant slope heights, and varying the slope angle and the block size of the falling rock, the number of blocks that pass the ditch line to reach the highway during the simulations was recorded. The results of this analysis are described below for one example for a slope of height 60'.

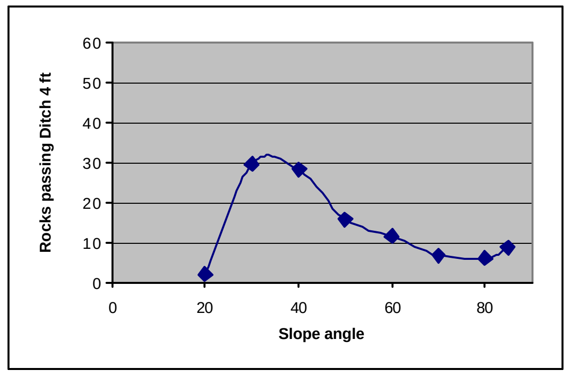
Slope Height 60'

Block size	20^o	30^o	40^o	50^o	60^o	70^o	80^o	85^o
5	12	39.2	33.8	22.8	14.6	4.4	5	3
4	2	29.6	28.2	15.8	11.6	6.8	6	8.8
3	0	15.8	22.2	14.6	10.4	6.8	9.2	26.8
2	0	1	10	11.8	8.8	10	10	45.4
1	0	0	1	2.8	7.2	13.6	12.8	55.8

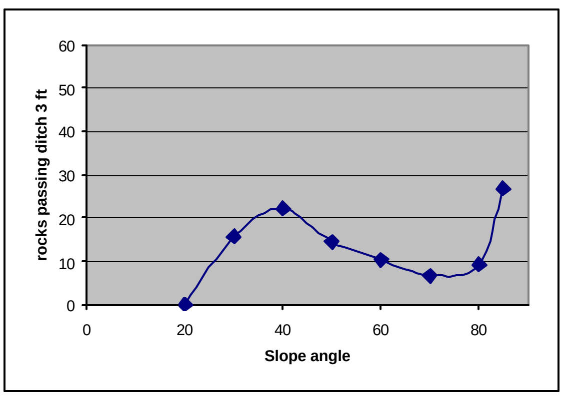
The graphs below have been drawn to show the relation between slope angle and rocks passing the ditch for different block sizes.



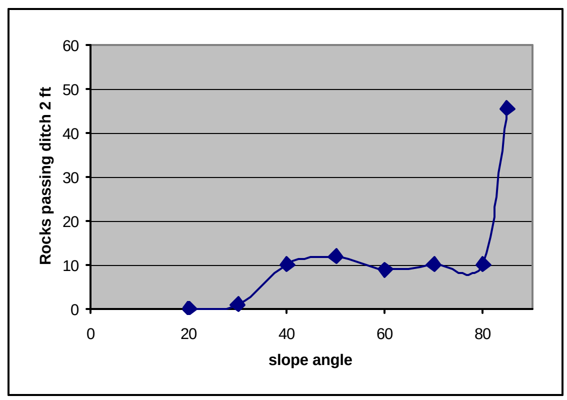
Block size = 5 ft



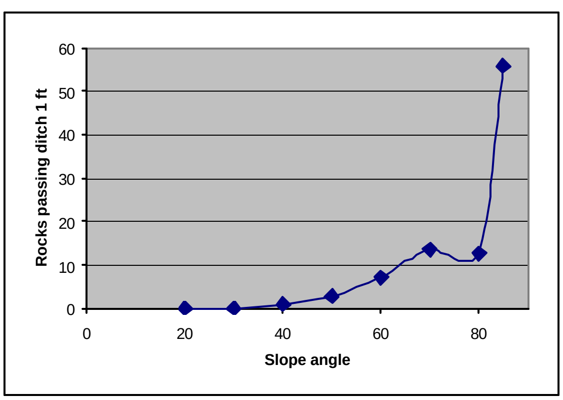
Block size = 4 ft



Block size = 3 ft



Block size = 2 ft



Block size = 1 ft

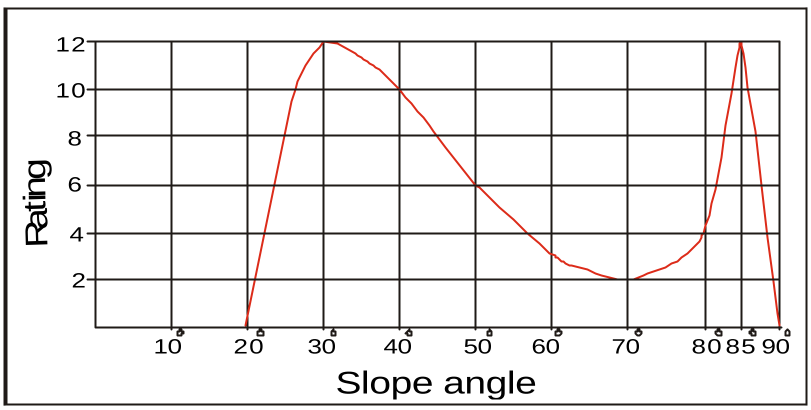
The following conclusions have been reached:

1. The most critical slope angle is 30° for the block sizes of 4 and 5' diameter.
2. For block sizes of 3', 40 and 85° (85° only for high slope) are critical.
3. For 2' blocks 40 and 50° for both high and low slope heights and 85° degree for high slopes are critical.
4. For 1' blocks 50° is critical for low slope heights but for high slopes 70 and 85° are critical.
5. For slope angles above 85° (i.e. vertical slopes), most blocks of all sizes will fall into and be contained by the ditch.

Summary:

1. If the slope angle > 85 the large blocks will fall down to the ditch without any problem to the road. The consequence increases as the slope decreases until about 30°, as the larger blocks *roll* down the slope.
2. If the slope angle is < 80°, there are few problems with small blocks that cannot mobilize enough energy to roll. However on slopes >80° and less than 90°, small block tend to *bounce* off the rock face,

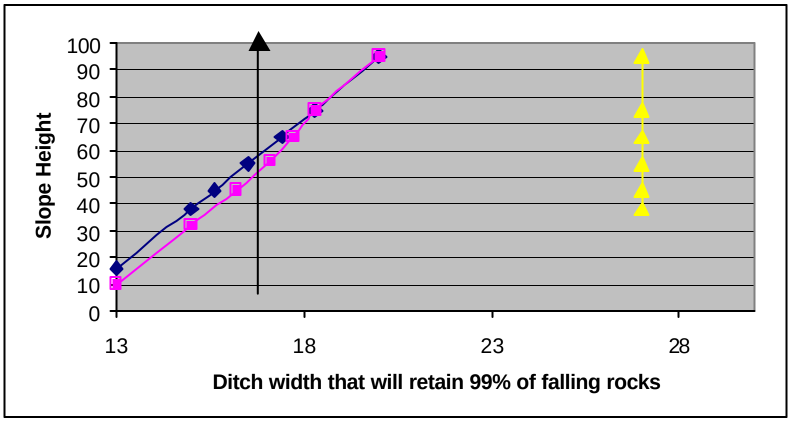
From these CRSP analysis results, the individual curves are added, to derive this compose relationship:



5.1.7.3 Determination of required maximum ditch width for rating

The design criteria for a ditch below a vertical rock cut are given below. From this curve we can see that ditch width 15 ft is very adequate (for a 60' slope). This is because the blocks will not roll away instead will fall down vertically. There are virtually no flat ditches in Missouri.

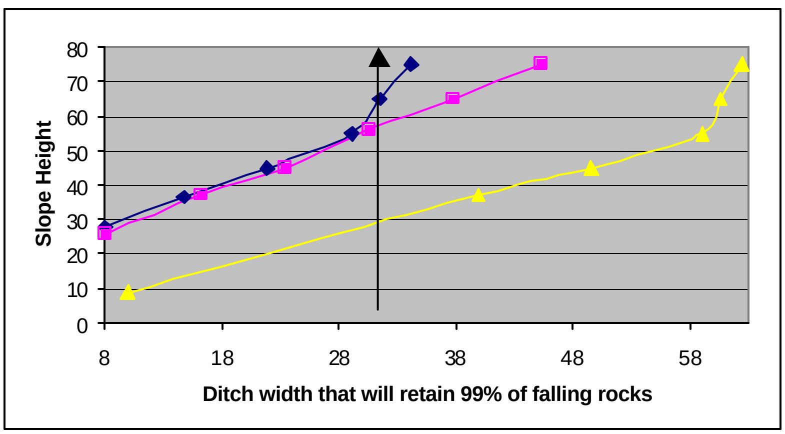
Vertical cut



(blue for ditch 1V:4H , pink for ditch 1V:6H, yellow for flat ditch)

The design criterion for ditch width in a slope of 75° is given below. From this curve, take a 30 ft width for the ditch design is adequate because the most rock cuts in Missouri are less than 60 to 70 ft.

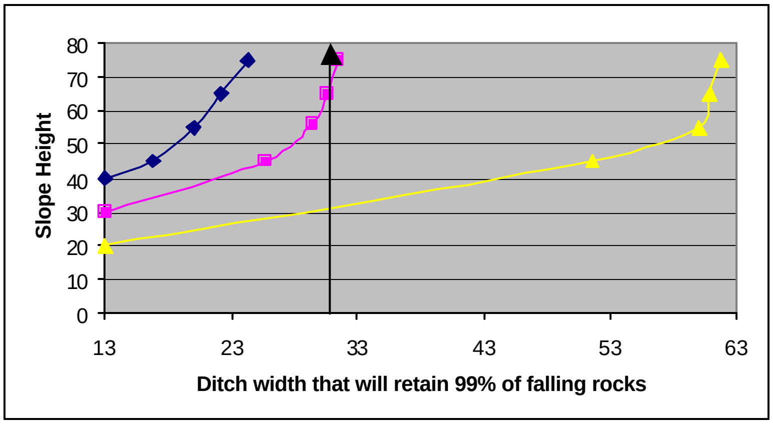
75° cut



(blue for ditch 1V:4H , pink for ditch 1V:6H, yellow for flat ditch)

The design criterion for ditch width with a slope angle 63 degree is given below. A 30 ft ditch design width is adequate because the most rock cuts in Missouri areas less than 60 to 70 ft.

63° cut



(blue for ditch 1V:4H , pink for ditch 1V:6H, yellow for flat ditch)

Note: Flat ditches are uncommon in Missouri rock cuts.

5.1.7.4 Average vehicle risk (AVR)

This below equation is a modified version of the one used by RHRS (Oregon 1993). Upon consultation with MODOT personnel the number of lanes was added to the equation:

$$AVR\% = \frac{\text{ADT (cars/day) x slope length (miles) x 100\%}}{\text{Posted speed limit (miles/hour)* number of lanes}}$$

5.1.7.4 Rock Face Strength (RFS)

The most adequate method for the strength of the intact rock is the uniaxial compressive strength, which is typically determined by laboratory tests. However, it is necessarily to assess the strength in the field without using laboratory tests.

There are many methods by which it is easy to determine the strength of the rocks:

1. ISRM (International Society of Rock Mechanics) suggested a method for the quantitative description of discontinuities in rock masses and can be helpful to assess the uniaxial compressive strength from a manual index tests performed on rock specimens with a pocket knife and /or a geological hammer (ISRM, 1978).

2. The second method uses charts with qualitative designations corresponding to quantitative values of rock strength (Geological Society Engineering Group Working Party, 1995a)

For strength of the rock face materials, we use the same description as the MODOT manual:

Rock strength	Class NO.	Description	R
Very strong rock	4	> 14504 psi, many blows by the hammer needed to fracture the rock	0
Strong rock	3	7252 – 14504 psi, several blows to fracture the rock	3
Moderately strong rock	2	3626 – 7252 psi, A firm blow needed to fracture the rock	6
Weak rock	1	725 – 3626 psi, can indent the rock with a pick	9
Very weak rock	0	145 - 725 psi, can crumble by hand	12

5.1.7.5 Block Size (BS)

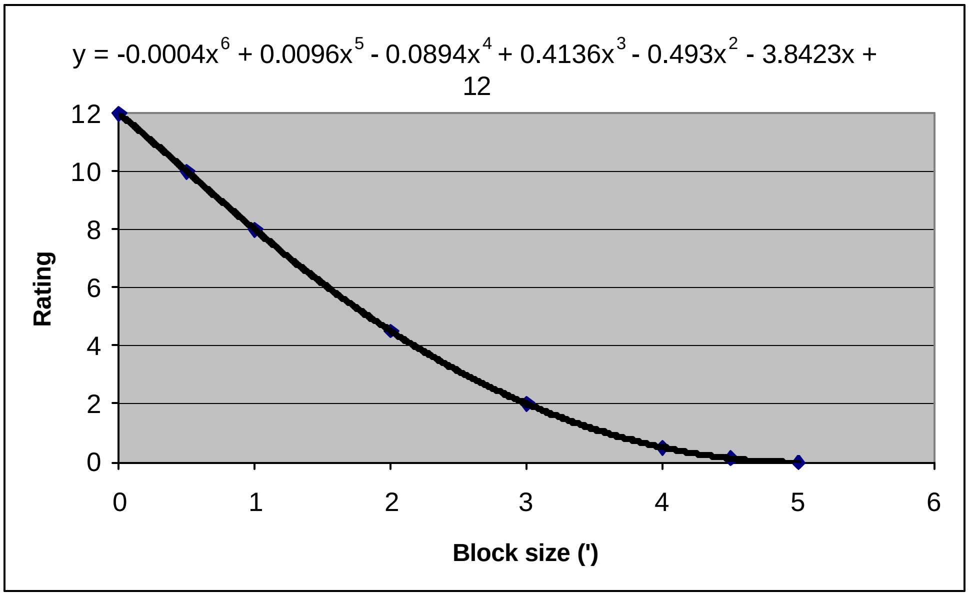
According to the RHRON system , block size is the inverse of the average joint spacing which is measured along the rock cut face, it is a very important factor to measure the quality of rock mass, and used to determine the degree of brokenness or instability of joints. On the other hand RHR system uses block size or quantity of rock fall per event to represent which rock fall event is most likely to occur. So if the individual blocks are typical of the rock fall, then block size will be used for scoring, but if a mass of broken rock tends to be the dominant type of rock fall, then the quantity per event will be used.

In MORF RS the average value of the block size from the rock cut face is used; this value represents the block size of the rock cut face.

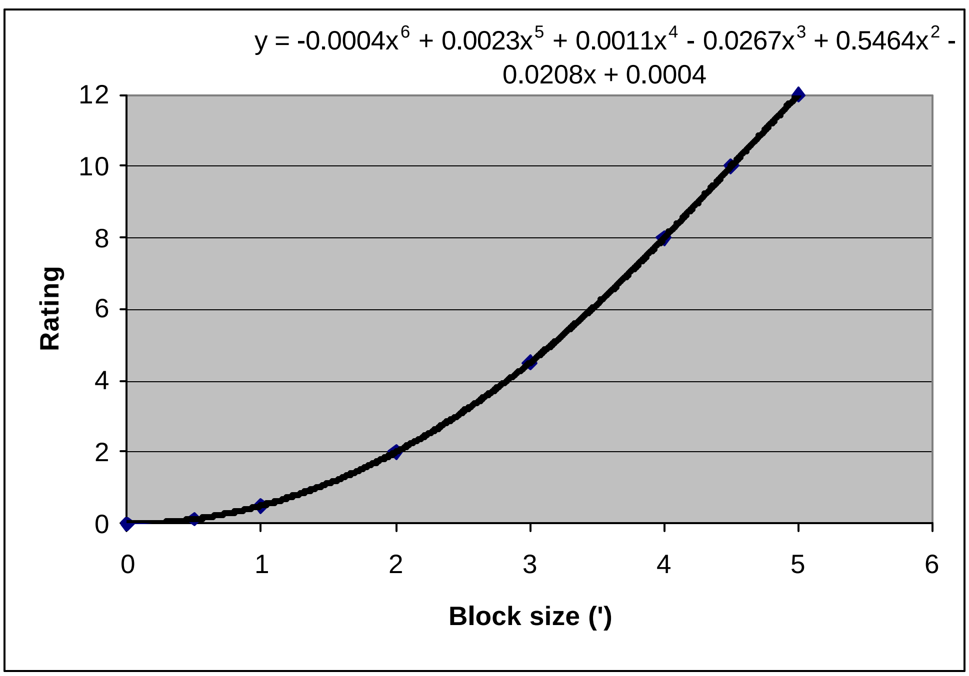
On the risk side, it is generally accepted that the larger the block size, the less likely failure is.

On the consequence side, there is a relationship between the block size and kinetic energy, which is needed for blocks to reach the highways. From CRSP results, it is clear that the large blocks increase the consequence effect, and the relation between block size and the energy is not linear and the relationship found from using CRSP is applied here.

For risk side rating:



For consequence side rating:



5.1.7.6 Ditch shape (DS)

This factor is rated to deal with the rolling and bouncing blocks especially if a bad bench or sloped rock face is encountered. The parameter classification comes from the ditch design manual and is modified to cover most categories we have in Missouri rock cuts.

Ditch shape	Flat	Slight back slope (1V:8H) 7°	Moderate back slope (1V:6H) 9°	Large back slope (1V:4H) 14°
Class Number	3	2	1	0
Rating	12	8	4	0

5.1.7.7 Adversely Oriented Discontinuities

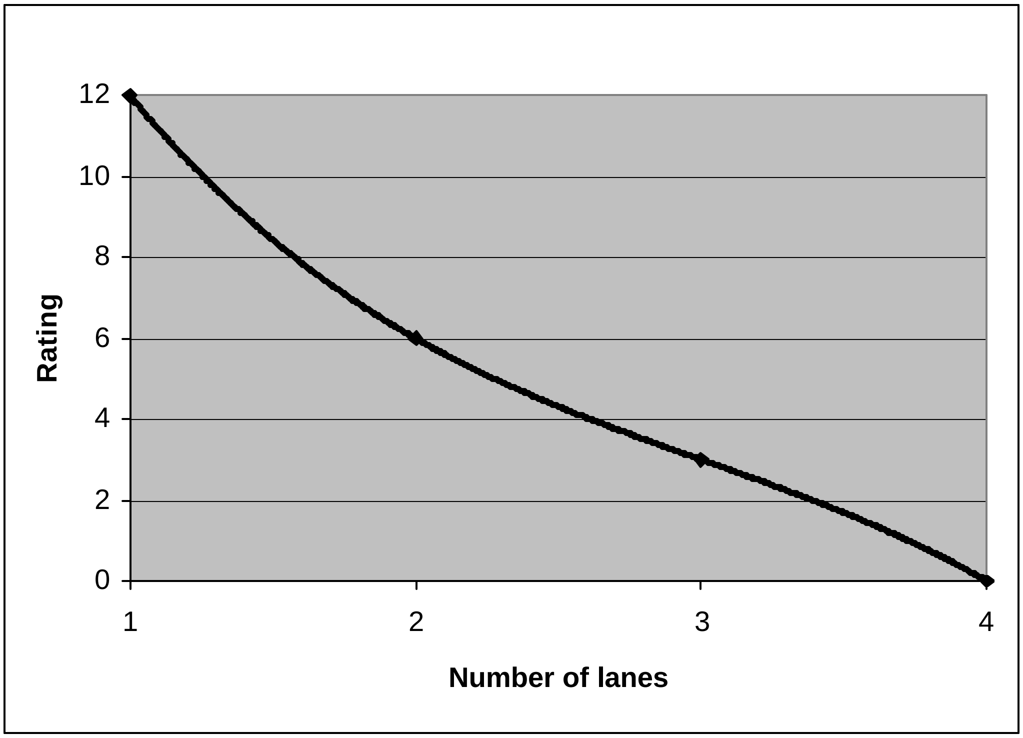
This is related to sensitivity analysis performed for worst case scenario for the discontinuity orientation and factor of safety by using the computer program Geoplane Slide analysis v. 0.5 1992 N. H. Geo. Consulting Ltd. (which is a limited equilibrium analysis), and also from the data derived from Hoek and Bray (1981) which considers the variation of the factor of safety with the slope angle of the discontinuities.

	Favorable	Fair	Unfavorable	Very Unfavorable
Class No.	0	1	2	3
Dip angle of discontinuity	< 20	20 – 45	45 - 65	65 – 90
Rating	0	4	8	12

5.1.7.8 Number of lanes (NOL)

A non-linear relationship is used here because the difference between moving from 1 to 2 lanes is more significant than moving from 2 to 3 lanes, in terms of the driver's ability to avoid fallen rock on the road and other vehicles. This equation was derived with consultation with MODOT personnel.

NOL	One lane	Two lanes	Three lanes	Four lanes
Rating	12	6	3	0



5.1.7.8 Average daily traffic (ADT)

ADT	> 500 Cars / day	5000 Cars / day	10000 Cars / day	15000 Cars / day	20000 Cars / day
Rating	0	3	6	9	12

Using the data from the Missouri Department of Transportation, “TRAFFIC VOLUME AND COMMERCIAL VEHICLE COUNTS 2000” and by consulting with MODOT personnel it was determined that the classes for this parameter must be 500 to 20000 cars per day.

5.1.7.9 Expected Rock fall Quantity

This is a subjective quantitative factor which is used to determine the ditch effectiveness, by calculating the ratio of expected rock fall quantity to the ditch volume.

5.1.7.10 Determination of other parameters

The remainder of the parameters ratings were derived empirically by field investigation and, based on the concepts that other rating systems used, with modifications to be compatible with the environment of the geological conditions in Missouri. New factors such as rock face instability, karst effect, and bench effect has been developed for this rating system, because these factors are very dominant in Missouri Highway rock cuts.

1. Rock face instability is a qualitative factor used because maintenance records are not available for most of the rock cut sites. This rating of this factor was set to a range between 0 (no evidence of rock in the ditch) to 12 (evidence of many failures with a lot of debris).

2. Face irregularity is a parameter used by different rating systems. The RHRON system base this on the amount of shotcrete needed make this face smooth. In MORFH RS the same idea is used. This factor is related to bad blasting and weathering effects. The rating of this factor was set to a range between 0 (smooth face) to 12 (highly irregular face with steps everywhere).

3. Face looseness is used by the RHRON system to characterize the number of open joints that are visible on the face, and their apertures. In MORFH RS the rating of this factor was set to how much of the face was covered by loose blocks. The rating of this factor was set to a range between 0 (no loose blocks on the face) to 12 (all of the face covered by loose blocks).

4. Weathering considers both the deterioration of the rock and differential erosion on the face (oversteepened slopes and unsupported rock units). Also the rate of erosion on the rock cut slope is related to the potential for a further rock fall events (Rock Slope Stability, 1999). There are different methods used to rate the weathering factor along the rock slope such as the RHR, in which they used two parameters which are differential erosion features and difference in erosion rate. Another method is by using a weathering chart in which the grade of weathering was recorded by using a charts example for that by (Geological Society Engineering Group Working Party, 1995b). In the MORFH RS both of the difference in weathering rate and differential erosion features are used. The rating of this factor was set to a range between 0 (no evidence of weathering) to 24 (major erosional features and many overhanging areas present). The rating for weathering is double the rating value for other factors because weathering is so important factor in Missouri rock falls.

5. Water on face is used by most of the rock fall hazard rating systems, because the presence of water pressure has a great influence on the stability of any rock face. It will increase the weathering rate, soften the weakest materials, and decrease effective stress along joints. The rating criteria is similar to RHRON; the rating is from 0 (dry) to 12 (water flowing from face).

6. Decision site distance is a factor that will determine if the driver will see the falling rocks on the road or not and if he can see it is he possibly stop his car before hitting the rock. Some systems express this as a percentage of a required sight distance (RHRON). In the MORFH RS a visual determination of the decision sight distance is used, which depends on different factors as curvatures on the roads (vertical and horizontal), presence of visual obstructions such as trees, which will obscure the drivers sightlines. The rating of this factor was set to a range between 0 (adequate to avoid rock on the highway) to 12 (rock fall zone is obscured by curves or other obstacles).

7. Karst effect is a new factor developed specifically for MORFH RS. The presence of karst features along the rock cut in the highways clearly will increase the instability of these cuts especially where sinks are filled by different types of blocks with weak cemented materials. The mere presence of carbonate rocks that are susceptible to karst are rated, because of the chance that there is a sinkhole or other feather hidden just behind the face. The rating of this factor was set to a range between 0 (absence of carbonate rock) to 12 (large karst features infilled with weak materials).

8. Bench effect is a new factor created for MORFH RS to deal with the bad bench effects. By using this factor we can differentiate between if the bench has a negative or positive effect on the highways in terms of allowing fallen rock to reach the road.

9. Expected rock fall quantity is a new factor added to the MORFH RS which is used to estimate the expected rock fall quantity from a rock cut. This factor is depends on visual estimation; the height and the depth of a 1 foot typical column of the rock cut estimated.

In each case ratings were classified and reclassified until a satisfactory scheme emerged.

5.2 The MORFH Rating System (User input vs. internal calculations)

The MORFH rating system includes 23 factors. The system includes 9 factors for risk, 11 factors for consequence, and 3 adjustment factors as described below. These factors have been organized into risk (of failure) and consequence (of failure) categories, and identified based on how the factors are evaluated:

A-Risk Factors	**Rating**
1- Slope Height*	0-12
2- Slope Angle*	0-12
3- Rock fall Instability (History)**	0-12
4- Weathering Factor***	0-24
5- Strength of the intact rocks***	0-12
6- Face Irregularity***	0-12
7- Face Looseness***	0-12
8- Block Size*	0-12
9 -Water On Face***	0-12

B-Consequence Factors	**Rating**
1- Ditch Width*	0-12
2- Ditch Shape*	0-12
3- Ditch Volume*	0-12
4- Rock fall Quantities (Expected)*	0-12
5- Slope Angle*	0-12
6- Shoulder Width*	0-12
7- Roadway Width*	0-12
8- Average Daily Traffic (ADT) **	0-12
9 -Average Vehicle Risk ****	0-12
10 -Decision Sight Distance (DSD)*	0-12
11- Block Size*	0-12

C-Adjustment Factors/Risk	**Rating**
1- Dip angle of discontinuities***	0-12
2- Karst Factor***	0-12

D-Adjustment Factors/Consequence	**Rating**
1- A- Ditch Capacity Exceedence****	0-15

* Factors that can be measured on computer scaled images
** Factors that can be made available by MODOT
*** Factors that require on-site qualitative assessment
**** Factors that are calculated based on other input values

MORFH RS is designed to be as complex as required, but have as simple as possible a user interface.

5.2.1 MORFH Rating System – User input

There are two ways to provide data for the system, either using real measured or estimated value or using a class number corresponding to descriptive ratings. In the case of descriptive ratings, there are nominally five ratings or class numbers reported as 0 – 4, however, half increment ratings are allowed, e.g. 2.5.

A- Risk Factors	**Values**
1- Slope height	0 - 60'
2- Slope angle	30 - 90°
3- Rock fall instability	0 - 4.0 (class number)
4- Weathering factor	0 - 4.0 (class number)
5- Strength of the intact rocks	0 - 4.0 (class number)
6- Face irregularity	0 - 4.0 (class number)
7- Face looseness	0 - 4.0 (class number)
8- Block size	0.1 - 5'
9- Water on face	0 – 4.0 (class number)

B- Consequence Factors	**Values**
1- Ditch width	0 - 15' or 0 – 30'
2- Ditch volume	0 - 30 cubic feet/foot
2- Ditch shape*	0 – 3 (class number)
3- Rock fall quantities (Expected)	0 - 40 cubic feet/foot
(4- Slope angle	*20 – 90° , same value as in risk factor)*
5- Shoulder width	0 - 12'
6- Number of lanes	1 - 4 lanes
7- Average daily traffic (ADT)	0 - 20,000 cars per day
8- Average Vehicle Risk	calculated from:
Speed Limit	40 - 70 mph *(required for AVR)*
Hazard rock cut length	100 - 600' *(required for AVR)*
9- Decision Sight Distance (DSD)	0 - 4.0 (class number)
(10- Block Size	*0.1 - 5' , same value as in risk factor)*

C- Adjustment Factors	**Values**
1- Adversely Oriented Discontinuities	0 – 3 (class number)
2- Karst Factor	0 – 3 (class number)
3- Ditch Capacity	1 – 4 (class number)

* Ditch shape used in place of ditch volume for non-vertical cuts or where there is a bad bench

5.2.1.1 User input- Using Microsoft Word® user interface

The MORFH rating system in its current form uses an Excel® OLE® object for data input. Figure 58 shows the Excel spread sheet, which is designed to accept input values for the system, either a physical measurement or a class number. The object calculates ratings for each factor, and determines overall risk-consequence rating as well as plotting the graph. The user needs only to enter the white fields in Figure 58, and the ratings are calculated automatically. Where real measurements are available, they are entered directly. For descriptive parameters the ordinal values (class numbers) are entered.

The object can simply be cut and pasted into a word document for reporting purposes. In the future, reporting will be done directly from the RockSee program.

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	40		8	Ditch Width	25		2
Slope Angle	75		9	Ditch Shape	0		0
Rockfall History	2		6	Ditch Volume	40		0
Weathering	2.5		15	Slope Angle	75		5
Rock Strength	2		6	Shoulder Width	13		0
Face Irregularities	2		6	Lanes Number	2		6
Face Looseness	3		9	Average daily Traffic	13000		7.8
Block Size	2		5	Rockfall Quantity	5		1.5
Water on Face	3		9	Average Vehicle Risk	70	300	2.6
	Joint	Sinkh.		Design Sight Dist.	1		4
Adjust. Factor	0	1	4	Block Size	2		2
Total			64	Adjust. Factor	1.0		0.0
				Total			23.5

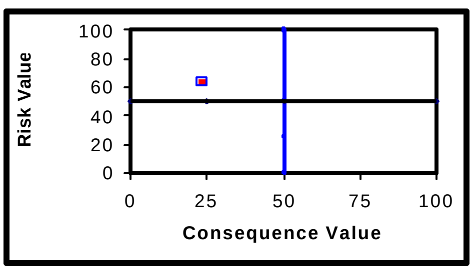


Figure 58: Excel spread sheet input object.

5.2.2 MORFH Rating System – Internal calculations

Table 7: Risk – Consequence rating system
Risk factors

Slope height (ft)	10	20	30	40	50	60^+
Rating	2	4	6	8	10	12

Slope angle	30^o	40^o	50^o	60^o	70^o	80^o	90^o
Rating	0	2	4	6	8	10	12

Rock fall Instability	Class No.	Description	R
Completely unstable	4	Rocks often fall in this area and there is considerable evidence for that in the ditch and from maintenance records; this will be in sites where severe rock fall events are common (a lot of debris in ditch).	12
Unstable	3	Rocks fall occasionally from time to time; the rock falls will occur frequently during certain times of the year, but will not be a significant problem during other times; this also is used where significant rock falls have occurred in the past (several blocks in the ditch)	9
Partially stable	2	Few rocks fall; rock falls can be expected several times per year, usually during storms. Few blocks in the ditch (one to two).	6
Stable	1	Very few blocks fall during a year and only during a severe storms	3
Completely stable	0	No rock falls; no historical and physical evidence for any rock fall in the area	0

Weathering factor	Class No.	Description	R
High	4	Major erosion features are present, there are many overhanging areas along the rock cut, differential erosion is evident along the rock cut	24
Moderate	3	Some erosion features are present, differential erosion features are large and numerous throughout the rock cut	18
Low	2	Minor differential erosion features appear widely distributed throughout the area, the differential erosion rate is limited	12
Slightly	1	Few differential erosion features, and the erosion rate is very low	6
Fresh	0	No evidence for the weathering and the walls are smooth and planar	0

Rock face strength	Class No.	Description	R
Very hard rock	4	> 2610 (tsf), can not be scratched by knife or sharp pick, several hard blows by the hammer needed to fracture the rock	0
Hard rock	3	1040 – 2610 (tsf), can be scratched with knife or sharp pick, Hard hammer blows required to detach hand specimens	3
Moderately hard	2	520 – 1040 (tsf), Required one hammer blow to fracture	6
Medium rock	1	260 – 520 (tsf), can be grooved 2mm (0.05 in) deep by firm pressure of knife	9
Soft rock	0	< 260 (tsf), can be peeled with a pocket knife, small, thin pieces can be broken by finger pressure	12

Face irregularity	Class No.	Description	R
Very highly irregular face	4	There are many joints and overhanging features, irregular features everywhere throughout the site, the face is stepped everywhere	12
Highly irregular face	3	Much the face is irregular and there are many joints and stepped faces	9
Moderately irregular face	2	There are many irregular areas in the face	6
Slightly irregular face	1	There are some irregular areas along the face	3
Smooth face	0	Very smooth face	0

Face looseness	Class No.	Description	R
Very high loose material	4	The face is completely covered by loose blocks	12
Highly loose material	3	Much of the face is covered by loose blocks	9
Moderately loose material	2	Some of the face is covered by loose blocks	6
Few loose material	1	Little of the face is covered by loose blocks	3
No loose material	0	There are no loose blocks on the face	0

Block size	Description	R
Massive	Blocks are large and average joint spacing 5 ft	0
Moderately blocky	Average block size is 2.5 ft	4
Very blocky	Average block size is 1 ft	8
Completely crushed	Intact rock has the character of a crushed run aggregates, joint spacing is less than 0.5 ft	12

Water on the face	Class No.	Description	R
Dry	0	There is no water on the face	0
Damp	1	There is evidence of water on the face	3
Wet	2	There is evidence of significant water on the face	6
Dripping	3	Water drips from the face	9
Flowing	4	Water flows from the face	12

Consequence factors

(for vertical rock cuts)

Ditch width (ft)	0	5	10	15
Rating	12	8	4	0

(for bad bench or non-vertical cut)

Ditch width (ft)	*0*	*10*	*20*	*30*
Rating	*12*	*8*	*4*	*0*

(For bad bench and / or slope rock cut face)

Ditch shape	*Flat*	*Slight back slope (1V:8H) 7°*	*Moderate back slope (1V:6H) 9°*	*Large back slope (1V:4H) 14°*
Class number	*3*	*2*	*1*	*0*
Rating	*12*	*8*	*4*	*0*

Ditch volume (ft^3)	0	5	10	15	20	25	30
Rating	12	10	8	6	4	2	0

Expected rock fall quantity	Description	R
> 40 cubic feet per linear foot	The face is completely loose and the expected volume of falling rocks will be about 40 cu ft/ft	12
30 cubic feet per unit foot	Most of the face is loose and the expected volume of falling rocks will be 30 cu ft/ft	9
20 cubic feet per linear foot	Many areas of the face are loose and the expected volume of falling rocks will be 20 cu ft/ft	6
10 cubic feet per linear foot	Few areas on the face are loose and the expected volume of falling rocks will be 10 cu ft/ft	3
Less than 5 cubic feet per unit linear foot	There is no expected rock fall (there is no loose materials on the face)	0

Slope angle	20°	30°	40°	50°	60°	70°	80°	85°	90°
Rating	0	12	10	6	3	2	4	12	0

Shoulder width (ft)	0	3	6	9	12
Rating	12	9	6	3	0

Number of lanes	One lane	Two lanes	Three lanes	Four lanes
Rating	12	6	3	0

Average daily traffic	< 500 Cars / day	5000 Cars / day	10000 Cars / day	15000 Cars / day	20000 Cars / day
Rating	0	3	6	9	12

Average vehicle risk	Description	R
Low Risk	25% of the time the vehicle will be in the zone of rock cut	3
Medium Risk	50% of the time the vehicle will be in the rock cut zone	6
High Risk	75% of the time the vehicle will be in the zone of rock cut	9
V. High Risk	100% of the time the vehicle will be in the zone of rock cut	12

Decision sight distance	Class NO.	Description	R
Very limited	3	Distance is very small and there are many vertical and horizontal curves on the roads, vegetation obscures falling rock	12
Limited	2	There are some curves and obstacles on the road not giving the driver enough time to perceive that there are falling rocks on the road	8
Moderate	1	There are few curves and obstacles and the driver can control the vehicle easily because he sees falling or fallen rocks	4
Adequate	0	The road is completely straight with out any obstacles or curves and the driver can see the entire rock face and road at any time	0

Block Size	Description	R
Massive	Blocks are large and average joint spacing 5 ft	12
Moderately blocky	Average block size is 2.5 ft	8
Very blocky	Average block size is 1 ft	4
Completely crushed	Intact rock has the character of a crushed run aggregates, joint spacing is less than 0.5 ft	0

Adjustment factors

Adversely oriented discontinuities	Favorable	Fair	Unfavorable	Very Unfavorable
Class Number	0	1	2	3
Dip angle of discontinuity	< 20	20 – 45	45 - 65	65 – 90
Rating	0	4	8	12

Karst description	Class number	Rating
For the igneous, metamorphic, and not carbonate rocks	0	0
For carbonate rocks that possibly have karst features and not appear on the rock cut face or if we have a linear dissolution features	1	3
For the karst features that appear on the rock cut face and its width is 50 ft, filled by boulders and cobbles or undercut with weak materials	2	6
For the karst features that appear on the rock cut face and its width 100 ft wide, filled by boulders and cobbles with weak materials	3	9
For the karst features that appear on the rock cut face and its width 150 ft, filled by boulders and cobbles with weak materials	4	12

ERFQ/DV	1	2	3	4
Rating Value	0	5	10	15

5.2.3 MORFH Rating system – Outputs

The following figures show the one page report out put for the rating system, which consists of: Site location information (Road name, site number, and GPS coordinates), picture, rating chart, and rating graph. The site location information is manually entered; the picture is pasted in if the Excel version is used (Figure 59) or automatically loaded if the prototype RockSee report is used (Figure 60). The rating chart is interactive and linked to the graph. Changes can be made anytime to the rating system, and the changes are reflected in the graph.

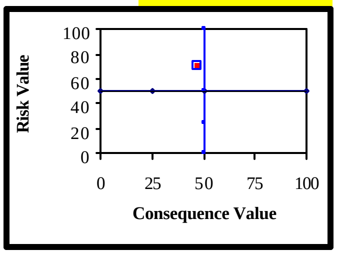
Road and Site Data **GPS Data**

Site	HYW	Elevation	Latitude	Longitude
1	63	1225 ft	N 37- 32.591	W 091-51.745

Site Picture Interface

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	30		6	Ditch Width	9		4.8
Slope Angle	65		7	Ditch Volume	12		7.2
Rockfall Instability	4		12	Slope Angle	65		2.5
Weathering	3		18	Shoulder Width	9		3
Rock Strength	0		12	Lanes Number	1		12
Face Irregularities	4		12	Average daily Traffic	5500		3.3
Face Looseness	4		12	Rockfall Quantity	10		3
Block Size	5		0	Average Vehicle Risk	60	968	8.4
Water on Face	2		6	Design Sight Dist.	0		0
	Joint	Sinkh.		Block Size	5		12
Adjust. Factor	**0**	0	0	**Adjust. Factor**	1		0
Total			**71**	**Total**			**46.8**

Risk Consequence parameters, Values, and calculations Interface

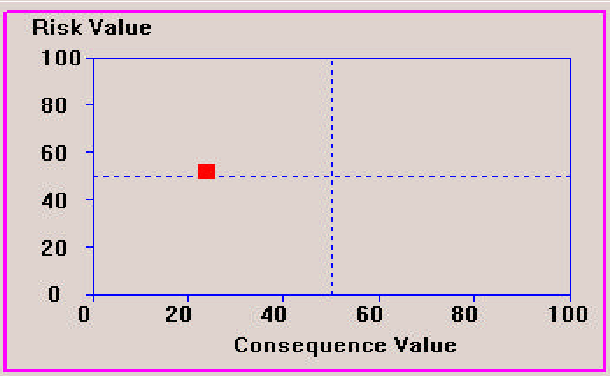


Risk - Consequence Graph Interface

Figure 59. Single page report to shows results of evaluation.

ANALYSIS REPORT

Location Information:	Site Number	Highway Name			
	55	63			
GPS Information:	Elevation	Latitude	Longitude		
	800 ft	N 38 20.234	W 91 33.678		
RISK FACTORS	Value	Rating	CONSEQUENCE FACTORS	Value	Rating
Rock cut height	22.0	4.4	Ditch Width	11.4	2.8
Slope angle	90.0	12.0	Ditch Volume	14.8	6.1
Rockfall history	1.5	4.5	Slope Angle	90.0	0.0
Weathering	1.5	9.0	Shoulder width	15.8	0.0
Strength of intact rock	3.0	3.0	Expected rockfall quantities	5.0	1.5
Face looseness	2.0	6.0	Number of lanes	1.0	4.0
Face irregularity	1.0	3.0	Average daily traffic	5500.0	3.3
Block size	2.5	3.1	Average vehicle risk	14.5%	1.7
Water on face	1.0	3.0	Design sight distance	0.0	0.0
	Joint Sinkh	Joint Sinkh	Block size	2.5	3.3
Adjust factors	0.0 1.0	0.0 4.0	Adjust factor	0.4	2.2
Total		52.0	Total		24.9



LOAD

SAVE

PRINT

Figure 60: Single page report to shows results of evaluation (using RockSee).

5.3 Error and sensitivity analysis

5.3.1 Introduction

Sensitivity analysis (SA) is the study of how the variation in the output of a model can be apportioned, qualitatively or quantitatively to different sources of variation, and of how the given model depends upon the information fed into it (Saltelli, 2000). On this basis we contend that SA is a prerequisite for model building in any setting, be it diagnostic or prognostic, and in any field where models are used. Models are developed to approximate or mimic systems and processes of different natures (e.g. physical, environmental, social, or economic), and of varying complexity. Many processes are so complex that physical experimentation is too time consuming, too expensive, or even impossible.

A mathematical model is defined by a series of equations, input factors, parameters and variables aimed to characterize the process being investigated. Input is subject to many sources of uncertainty including errors of measurement, absence of information and poor or partial understanding of the driving forces and mechanisms. This imposes a limit on our confidence in the response or output of the model. Further, models may have to cope with the natural intrinsic variability of the system, such as the occurrence of stochastic events.

Good modeling practice requires that the modeler provide an evaluation of the confidence in the model, possibly assessing the uncertainties associated with the modeling process and with the outcome of the model itself. Originally SA was created to deal simply with uncertainties in the input variables and model parameters. Over the course of time, the ideas have been extended to incorporate model conceptual uncertainty, i.e. uncertainty in model structures, assumptions, and specifications. As a whole, SA is used to increase the confidence in the model and its prediction by providing an understanding of how the model response variables respond to changes in the inputs, be they data used to calibrate it, model structures, or factors, i.e. the model independent variables.

The aim of sensitivity analysis is to estimate the rate of change in the output of a model with respect to changes in model inputs. Such knowledge is important for (a) evaluating the applicability of the model, (b) determining parameters for which it is important to have more accurate values, and (c) understanding the behavior of the system being modeled. Saltelli et al. 2000, present some basic types of calculation that can be used to measure sensitivity. The example they use the example of a dry cleaning bill that comprises the sum of a number of different items, C sub i. We could compute the derivative:

$$S_i = \frac{\partial C}{\partial C_i}$$

for each i where all the C sub i are fixed to some reference value, the "nominal" value. So the quantity C sub i is the local sensitivity index measuring the effect on C of perturbing C sub i around a reference value.

The fundamental difficulty in sensitivity analysis is ensuring that you have examined the range of variation in parameters and/or input variables and how they might work in a combined way. The general approach is to use sampling-based sensitivity analysis, which Saltelli defines as “a sampling based SA is one in which the model is executed repeatedly for combinations of values sampled from the distribution of the input factors".

In this work we conduct two different types of sensitivity analysis as follows:

3. Local SA, which determine the effect of the variation in each input factor when the others are kept at some constant level. The result is a series of partial derivatives, one for each factor, that define the rate of change of the output function relative to the rate of change of the input function.
4. Global SA the effects of variation in the inputs, as all inputs are allowed to vary over their ranges.

5.3.2 Analysis 1: Changing more than one parameter at the time

Sensitivity analysis is a means to determine the effect of those critical variables that, if changed, could considerably affect the factor of safety applicable to a particular design. The base parameters used to apply the sensitivity analysis on are listed in Table 8. In this sample we have values measured as length, volume, angles, and for descriptive parameters classes 0 to 4.0 in increments of 0.5.

Table 8: Base sample used in sensitivity and error analysis

Risk Factors	**Measurements**	**Descriptor**
Rock Cut Height	30 ft	
Slope Angle	70 degree	
Rock fall Instability		3
Weathering		2
Rock Face Strength		2
Face Irregularities		1
Face Looseness		2
Block Size	3 ft	
Water On Face		2
Consequence Factors	Measurements	Descriptor
Ditch Width	9 ft	
Ditch Volume	13.5 cu ft/ft	
Slope Angle	70 degree	
Shoulder Width	12 ft	
Number Of Lanes		1
Average Daily Traffic	5500 car/day	
Rock fall Quantity	30 cu ft/ft	
Average Vehicle Risk	500 ft	
Design Sight Distance		1
Block Size	3 ft	

In this analysis, several different types of sensitivity analyses were applied as show in Tables 9 to 12.

5.3.2.1 Sensitivity analysis: Changes in the rating due to measurement error using RockSee measurements only

Table 9 shows the results of applying the average error when taking measurements from RockSee, simultaneously for all parameters. For this analysis the rated parameters stay constant.

Table 9: Changes in the rating due to measurement error using RockSee.

Risk Factors	**Base**			**+ errors**			**- errors**		
	value		**rating**	**value**		**rating**	**value**		**rating**
Rock cut height	30		6	31.1		6	28.8		6
Slope angle	70		8	71.8		8.38	68		7.6
Rock fall instability	3		12	3		12	3		12
Weathering	2		12	2		12	2		12
Rock face strength	2		6	2		6	2		6
Face irregularities	1		3	1		3	1		3
Face looseness	2		6	2		6	2		6
Block size	3		2	2.5		3	3.5		1
Water on face	2		6	2		6	2		6
	Joint	Karst		Joint	Karst		Joint	Karst	
Adjustment Factor	0	0	0	0	0	0	0	0	0
Risk Value			51			52.3			49.6

Consequence Fact.	**Base**			**+ errors**			**- errors**		
	value		**rating**	**value**		**rating**	**value**		**rating**
Ditch width	9		4.8	8.46		5.23	9.54		4.4
Ditch volume	13.5		6.6	11.6		7.36	15.5		5.8
Slope angle	70		2	71.9		2	68		1.9
Shoulder width	12		0	11.1		0.9	12.9		0
Number of lanes	1		12	1		12	1		12
Average daily traffic	5500		3.3	5500		3.3	5500		3.3
Rock fall quantity	30		9	30		9	30		9
Average vehicle risk	65	500	4.0	65	534	4.3	65	466	3.7
Design sight distance	1		4	1		4	1		4
Block size	3		5	3		5	3		5
Adjustment Factor	2.22		4.9	2.58		6.34	1.93		3.7
Consequence Value			46.0			49.2			43.7

Risk parameters
The only two risk parameters that can be measured on the image are rock cut height and slope angle. The average error percentage that has been calculated (+ or –) is used, as in the following table:

	From manual measurements	Change of rating error due to computer error	Range in risk value due to the computer error
Risk Value	51	2.7%	49.6 – 52.3

From this table it can be seen that the measurement error will not significantly change the risk rating. Consequently the model is not too sensitive to the computer measurements.

Consequence parameters
There are many factors in the consequence rating that con be measured on images, including ditch width, ditch volume, slope angle, shoulder width, and average vehicle risk. The error in ditch width and ditch depth will affect the ditch volume, and the error in the rock cut length will influence on the average vehicle risk as the rock cut length one of the factor that we use to determine the average vehicle risk. By applying this error effect on these parameters and keep all other parameters in the consequence area constant, we got this result.

	From manual measurements	Change of rating error due to computer error	Range in consequence value due to the computer error
Consequence Value	46	5.5 %	43.7 – 49.2

From this table it can be seen that the measurement error will also not significantly change the consequences rating.

5.2.3.2 Sensitivity analysis: Changes in the rating due to measurement error using RockSee measurements and error in judgment for face irregularity category

Table 10 shows the results of introducing a ½ class error in one of the ratings (Face irregularities).

Table 10: Changes in the rating due to measurement error using RockSee plus error in judgment for face irregularity category.

Risk Factors	Base			+ errors			- errors		
	value		rating	value		rating	value		rating
Rock cut height	30		6	31.1		6	28.8		6
Slope angle	70		8	71.8		8.38	68		7.6
Rock fall instability	3		12	3		12	3		12
Weathering	2		12	2		12	2		12
Rock face strength	2		6	2		6	2		6
Face irregularities	1		3	1.5		4.5	0.5		1.5
Face looseness	2		6	2		6	2		6
Block size	3		2	3		2	3		2
Water on face	2		6	2		6	2		6
	Joint	Karst		Joint	Karst		Joint	Karst	
Adjustment Factor	0	0	0	0	0	0	0	0	0
Risk Value			51			52.6			49.0

Consequence Fact.	Base			+ errors			- errors		
	value		rating	value		rating	value		rating
Ditch Width	9		4.8	8.46		5.23	9.54		4.4
Ditch Volume	13.5		6.6	11.6		7.36	15.5		5.8
Slope Angle	70		2	71.9		2	68		1.9
Shoulder Width	12		0	11.1		0.9	12.9		0
Number Of Lanes	1		12	1		12	1		12
Average Daily Traffic	5500		3.3	5500		3.3	5500		3.3
Rock fall Quantity	30		9	30		9	30		9
Average Vehicle Risk	65	500	4.0	65	534	4.3	65	466	3.7
Design Sight Distance	1		4	1		4	1		4
Block Size	3		5	3		5	3		5
Adjustment Factor	2.22		4.9	2.58		6.34	1.93		3.7
Consequence Value			46.0			49.2			43.7

Risk parameters

The descriptive parameters are categorized by class number from 0 to 4.0. For the irregularity factor we assumed that the error due to the rater will be 0.5 of a class number which means for example instead of choosing a moderately irregular face (2.0) the rater will choose between moderate and high (2.5) or between moderate and slightly irregular (1.5).

	From manual measurement with no error for any descriptive factor	Change of rating error due to computer error and error in irregularity category	Range in risk value due to the computer error and error in irregularity category
Risk Value	51	3.6 %	49 – 52.6

From this table it can be seen that the measurement error plus rater error in face irregularity will also not significantly change the consequences rating.

5.2.3.3 Sensitivity analysis: Changes in the rating due to measurement error using RockSee measurements and error in judgment for weathering category.

Table 11 shows the results of introducing a ½ class error in one of the ratings (Weathering). Note that the weathering parameter has double the weight of the other parameters in MORFH RS.

Table 11: Changes in the rating due to measurement error using RockSee plus error in judgment for weathering category.

Risk Factors	**Base**			**+ errors**			**- errors**		
	value		**rating**	**value**		**rating**	**value**		**rating**
Rock cut height	30		6	31.1		6	28.8		6
Slope angle	70		8	71.8		8.38	68		7.6
Rock fall instability	3		12	3		12	3		12
Weathering	2		12	2.5		15	1.5		9
Rock face strength	2		6	2		6	2		6
Face irregularities	1		3	1		3	1		3
Face looseness	2		6	2		6	2		6
Block size	3		2	3		2	3		2
Water on face	2		6	2		6	2		6
	Joint	Karst		Joint	Karst		Joint	Karst	
Adjustment Factor	0	0	0	0	0	0	0	0	0
Risk Value			51			53.8			47.8

Consequence Fact.	**Base**			**+ errors**			**- errors**		
	value		**rating**	**value**		**rating**	**value**		**rating**
Ditch Width	9		4.8	8.46		5.23	9.54		4.4
Ditch Volume	13.5		6.6	11.6		7.36	15.5		5.8
Slope Angle	70		2	71.9		2	68		1.9
Shoulder Width	12		0	11.1		0.9	12.9		0
Number Of Lanes	1		12	1		12	1		12
Average Daily Traffic	5500		3.3	5500		3.3	5500		3.3
Rock fall Quantity	30		9	30		9	30		9
Average Vehicle Risk	65	500	4.0	65	534	4.3	65	466	3.7
Design Sight Distance	1		4	1		4	1		4
Block Size	3		5	3		5	3		5
Adjustment Factor	2.22		4.9	2.58		6.34	1.93		3.7
Consequence Value			46.0			49.2			43.7

Risk parameters

	From manual measurement with no error for any descriptive factor	Change of rating error due to computer error and error in weathering category	Range in risk value due to the computer error and error in weathering category
Risk Value	51	6%	47.8 – 53.8

From this table it can be seen that the measurement error plus rater error in weathering is slightly significant and changes the risk rating slightly (The system is more sensitive to weathering because the maximum rating for weathering is 24 as opposed to 12 for all the other categories.

5.2.3.4 Sensitivity analysis: Changes in the rating due to measurement error using RockSee measurements and error in judgment for all descriptive categories.

Table 12 shows the results of introducing a ½ class error in all the ratings (Weathering, Strength, Face irregularity, Face looseness, Block size, Water on face, and Decision sight distance).

Table 12: Changes in the rating due to measurement error using RockSee plus error in judgment for all descriptive categories.

Risk Factors	**base**			**+ errors**			**- errors**		
	value		**rating**	**value**		**rating**	**value**		**rating**
Rock Cut Height	30		6	31.1		6	28.8		6
Slope Angle	70		8	71.8		8.38	68		7.6
Rock fall Instability	3		12	3.5		12	2.5		12
Weathering	2		12	2.5		15	1.5		9
Rock Face Strength	2		6	1.5		7.5	2.5		4.5
Face Irregularities	1		3	1.5		4.5	0.5		1.5
Face Looseness	2		6	2.5		7.5	1.5		4.5
Block Size	3		2	2.5		2	3.5		2
Water On Face	2		6	2.5		7.5	1.5		4.5
	Joint	Karst		Joint	Karst		Joint	Karst	
Adjustment Factor	0	0	0	0	0	0	0	0	0
Risk Value			51			58.8			42.8

Consequence Fact.	base			+ errors			- errors		
	value		rating	value		rating	value		rating
Ditch Width	9		4.8	8.46		5.23	9.54		4.4
Ditch Volume	13.5		6.6	11.6		7.36	15.5		5.8
Slope Angle	70		2	71.9		2	68		1.9
Shoulder Width	12		0	11.1		0.9	12.9		0
Number Of Lanes	1		12	1		12	1		12
Average Daily Traffic	5500		3.3	550 0		3.3	5500		3.3
Rock fall Quantity	30		9	30		9	30		9
Average Vehicle Risk	65	500	4.0	65	534	4.3	65	466	3.7
Design Sight Distance	1		4	1.5		6	0.5		2
Block Size	3		5	3		5	3		5
Adjustment Factor	2.22		4.9	2.58		6.34	1.93		3.7
Consequence Value			46.0			50.9			42.1

Risk parameters
The descriptive parameters that varied are rock fall history, weathering, intact rock strength, face irregularities, face looseness, and water on slope.

	From manual measurement with no error for any descriptive factor	Change of rating error due to computer error and error in all descriptive categories	Range in risk value due to the computer error and error in all descriptive categories
Risk Value	51	16%	42.8 – 58.8

From this table it can be seen that the model is fairly sensitive if there is error in all the descriptive parameters, and the errors are systematic (all either contributing to increase the risk value or all contributing to decrease the risk value). In reality, unless the rater is highly systematically biased the errors are likely to cancel each other out.

Consequence parameters
The descriptive parameter that is used in the system is design sight distance. By applying this error effect on these parameters, which are descriptive and measured and all other parameters in the consequence area are constant as (average daily traffic, rock fall quantity, and block size) we get this result.

	From manual measurement with no error for any descriptive factor	Change of rating error due to computer error and error in all descriptive categories	Range in risk value due to the computer error and error in all descriptive categories
Consequence Value	46	8.8 %	42.1 – 50.9

From this table it can be seen that the model is moderately sensitive if there is error in the descriptive parameter (design sight distance), and the errors in the computer measurements.

5.3.3 Analysis 2: Changing only one parameter per time

The base ratings used in this analysis are in Table 13.

Table 13: Base sample for sensitivity analysis

Risk Factors	Value		Rating
Rock Cut Height	30		6
Slope Angle	70		8
Rock fall History	3		9
Weathering	2		12
Rock Face Strength	2		6
Face Irregularities	1		3
Face Looseness	2		6
Block Size	3		2
Water On Face	2		6
	Joint	Karst.	
Adjustment Factor	0	0	0
Risk Value			48.32

Consequence Factors	**Value**		Rating
Ditch Width	9		4.8
Ditch Volume	13.5		6.6
Slope Angle	70		2
Shoulder Width	10		2
Number Of Lanes	1		12
Average Daily Traffic	5500		3.3
Rock fall Quantity	30		9
Average Vehicle Risk	65	500	4.0
Design Sight Distance	1		4
Block Size	3		5
Adjustment Factor	2.222		4.889
Consequence Value			47.7

In this analysis the changes are made for one factor at a time and the effect of this factor on the risk and consequence value is observed. For the measurable factors the error percent determined by previous studies is used for the sensitivity analysis for the effect of these errors on the risk – consequence model. On the other hand for the descriptive factors we use a change of 0.5 and 1 of any class number and see the effect of that change on the mode (Tables 14 and 15).

Table 14: Changes in the rating due to measurement error using RockSee plus 0.5 class number error in judgment for all descriptive categories, risk side..

Value	Change in the Prediction	Predicted Rating Value	Risk Value	Change in the Risk value prediction %
Rock Cut height				
31.17	+ 3.9 %	6.22	48.52	0.41
30	0	6	48.32	0
28.8	- 3.9%	5.74	48.12	-0.41
Slope angle				
71.89	+ 2.7%	8.38	48.64	0.66
70	0	8	48.32	0
68	- 2.7%	7.6	47.99	-0.68
Rock fall instability				
3.5	+ 0.5	10.5	49.57	2.59
3	0	9	48.32	0
2.5	- 0.5	7.5	47.07	-2.59
Weathering				
2.5	+ 0.5	15	50.82	5.17
2	0	12	48.32	0
1.5	- 0.5	9	45.82	-5.17
Rock face strength				
1.5	+ 0.5	7.5	49.57	2.59
2	0	6	48.32	0
2.5	- 0.5	4.5	47.07	-2.59
Face irregularities				
1.5	+ 0.5	4.5	49.57	2.59
1	0	3	48.32	0
0.5	- 0.5	1.5	47.07	-2.59
Face looseness				
2.5	+ 0.5	7.5	49.57	2.59
2	0	6	48.32	0
1.5	- 0.5	4.5	47.07	-2.59
Water on face				
2.5	+ 0.5	7.5	49.57	2.59
2	0	6	48.32	0
1.5	- 0.5	4.5	47.07	-2.59

Table 15: Changes in the rating due to measurement error using RockSee plus 0.5 class number error in judgment for all descriptive categories, consequence side.

Value	Change in the prediction	Predicted Rating value	Consequence Value	Change in the Consequence value prediction %
Ditch width				
8.46	- 6%	5.23	48	0.628931
9	0	4.8	47.7	0
9.54	+ 6%	4.37	47.3	-0.83857
Ditch volume				
11.6	DW 6%	7.36	49.5	3.773585
13.5	DD 8.6%	6.6	47.7	0
15.5		5.8	46.1	-3.3543
Slope angle				
71.9	+ 2.7%	2.1	47.8	0.209644
70	0	2	47.7	0
68	- 2.7%	1.9	47.6	-0.20964
Shoulder width				
9.24	- 7.6%	2.76	48.3	1.257862
10	0	2	47.7	0
10.76	+ 7.6%	1.24	47.1	-1.25786
Rock fall quantity				
31.5	+ 5%	9.45	48.4	1.467505
30	0	9	47.7	0
28.5	- 5%	8.55	46.9	-1.67715
Design sight distance				
1.5	+ 0.5	6	49.4	3.563941
1	0	4	47.7	0
0.5	- 0.5	2	46	-3.56394

From these analyses, the effect of the error values for measurable parameters on the sensitivity of the rating system (Risk and Consequence values) is very small, except for ditch volume which is a little higher because ditch volume calculated from ditch depth and ditch width so both error values compound. For the descriptive parameters, the change in the class was 0.5 and 1 (1 is for the worst case for the rater). From that it appeared the sensitivity of the system for the change 0.5 class number is almost low as 5.16% except 7.12 and 10.34 for DSD and weathering factors respectively the value for weathering is higher. That is because we have high rating for this factor, and for DSD because the inner rating is different than other parameter Table 16.

Table 16: Sensitivity results of the error % of measurable factors and 0.5 class numbers.

Risk Factors	**Minimum Change in Risk %**	**Maximum change in Risk%**	**Range %**
Slope Height	-0.41	0.41	0.82
Slope Angle	-0.68	0.66	1.34
Rock fall Instability	-2.58	2.58	5.16
Weathering	-5.17	5.17	10.34
Rock Face Strength	-2.58	2.58	5.16
Face Irregularities	-2.58	2.58	5.16
Face Looseness	-2.58	2.58	5.16
Water On Face	-2.58	2.58	5.16
Consequence Factors	**Minimum Change in Consequence %**	**Maximum change in Consequence %**	**Range %**
Ditch Width	-0.84	0.63	1.47
Ditch Volume	-3.35	3.77	7.12
Slope Angle	-0.21	0.21	0.42
Shoulder Width	-1.26	1.26	2.52
Rock fall Quantity	-1.70	1.47	3.17
Design Sight Distance	-3.56	3.56	7.12

On the other hand when we change the class number by value 1 the sensitivity of the change in the Risk – Consequence values will be so high (Table 17).

Table 17: Sensitivity results of the error % of measurable factors and 1 class number.

Risk Factors	**Minimum Change in Risk %**	**Maximum change in Risk%**	**Range %**
Slope Height	-0.41	0.41	0.82
Slope Angle	-0.68	0.66	1.34
Rock fall Instability	-5.17	5.17	10.34
Weathering	-10.35	10.35	20.70
Rock Face Strength	-5.17	5.17	10.34
Face Irregularities	-5.17	5.17	10.34
Face Looseness	-5.17	5.17	10.34
Water On Face	-5.17	5.17	10.34
Consequence Factors	**Minimum Change in Consequence %**	**Maximum change in Consequence %**	**Range %**
Ditch Width	-0.84	0.63	1.47
Ditch Volume	-3.35	3.77	7.12
Slope Angle	-0.21	0.21	0.42
Shoulder Width	-1.26	1.26	2.52
Rock fall Quantity	-1.67	1.47	3.14
Design Sight Distance	**-6.92**	6.92	13.84

From these analyses it is obvious that an error in any one parameter of 0.5 is negligible, but if there is a systematic error in all parameters at once the overall MORFH RS rating may be seriously wrong. Also, if the error in the parameter is 1.0, the overall rating will be even more significant.

5.4. RockSee computer program

5.4.1 Introduction

Video images of highway right-of-ways are routinely done for inventorying of highway assets and measurements of such attributes as sign placement (Maerz and McKenna, 1999). These systems are usually complex and expensive requiring complicated vehicle instrumentation, but may have very precise measurements.

For the RockSee system, a much more inexpensive system was required. It was developed using state of the art but inexpensive off the shelf hardware and purpose designed software. The goal was to make a cost effective system that can be used to preview road cuts, and to make simple measurements, where extreme accuracy and precision are not required.

5.4.2 Video preview

The concept of using video images is simple. Video images can be taken at highway speeds by technicians, digitally recorded, and evaluated back in the office by the engineer or geologist. The engineer or geologist can quickly select the areas where stability may be an issue, and pick locations for site evaluations, preparing hard copies of images to take to the field to facilitate the identification of problem areas. The digital video is recorded on mini-DV tapes, and transformed to AVI files using commercially available software such as Adobe Premiere. The AVI files are then loaded into the AVI viewer, and individual rock cuts can be viewed (Figure 61). Areas that appear problematic can be identified for later detailed analysis. Hardcopies of images of problematic areas can be printed to be used as references in the field.

5.4.3 Video measurements

Measurements can be made on single images without extensive vehicle instrumentation and modifications. Although not as accurate as manual measurements in the field, the measurements are more than accurate enough for the purposes of providing input data for rock hazard rating system. The system simply requires a simple camera setup, scale calibration, and appropriate identification of measurement object endpoints.

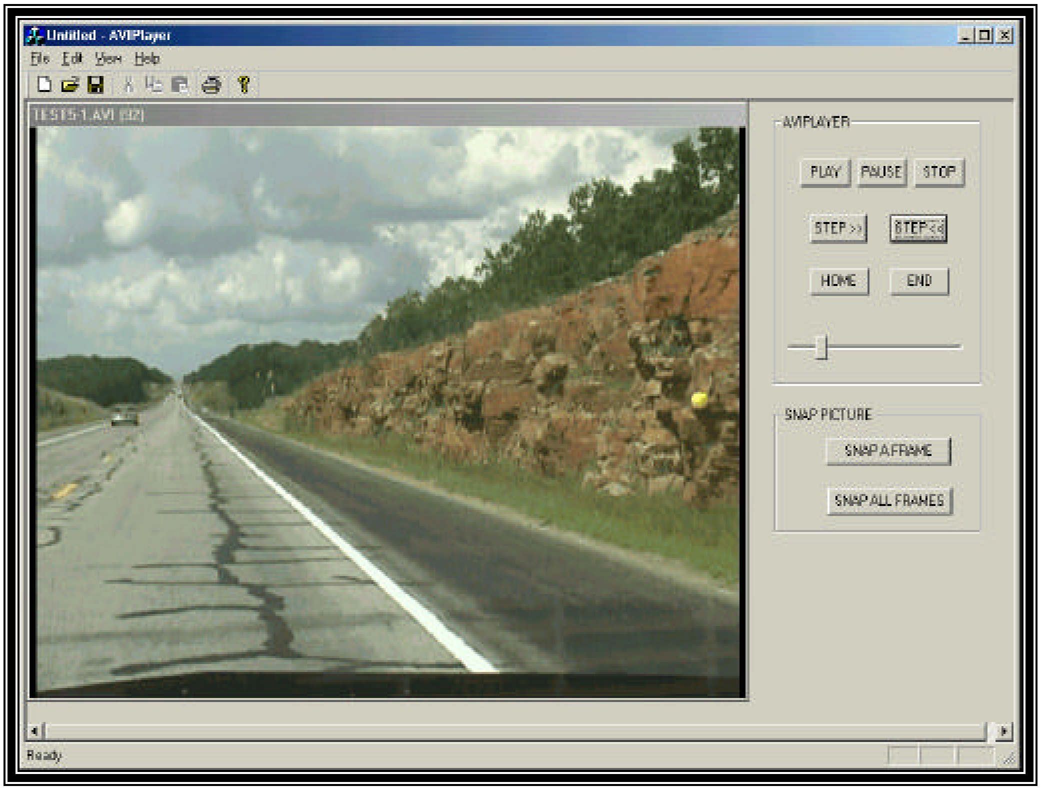


Figure 61: AVI- Player interface

5.4.4 Camera setup

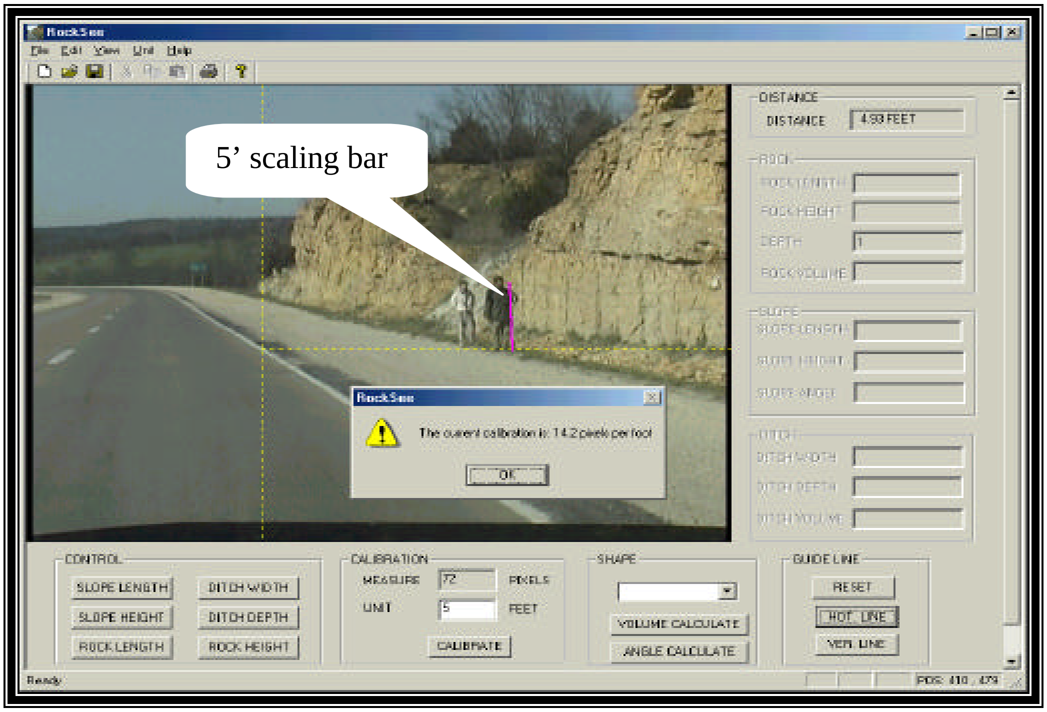
The camera setup consists simply of vertical and horizontal alignment of the camera, and setting the zoom factor on the lens. Vertical alignment and zoom factors are set in tandem, to ensure that the picture encompasses the top of typical road cuts as well as the plane of the highway. Typically the alignment is near horizontal, or pointing slightly up, with the zoom set to a fairly wide angle, but not so wide as to include the hood of the vehicle in the image.

Horizontal alignment should be set to about 10º to the right of the direction of travel. This is best accomplished by stretching a tape measuring 100' in the direction of travel, stretching a second tape measure 17.6' at 90º from the end of the first and to the right, placing a vertical object, and centering the camera on that object (Figure 62).

Figure 62: Aiming the camera at an angle of 10º to the left of the direction of travel vector.

5.4.5 Calibration

Scale calibration is required, this can be done by taking an image such as in Figure 63, with a scaling object in the image. The portion of the image that the scaling is valid for, is defined by a vertical plane, perpendicular to the camera vector, and that passes through the point defined by the painted white road edge line and the vertical dotted line that is arbitrarily placed 1/3 of the way into the image from the left hand side. This scale remains constant for that position in all images, but makes the assumption that the roadway is straight between the vehicle and the plane of measurement. Alternatively, the road width if constant can be used as a scaling object. This allows measurements to be made in a vertical plane perpendicular to the camera vector, anywhere in the image.



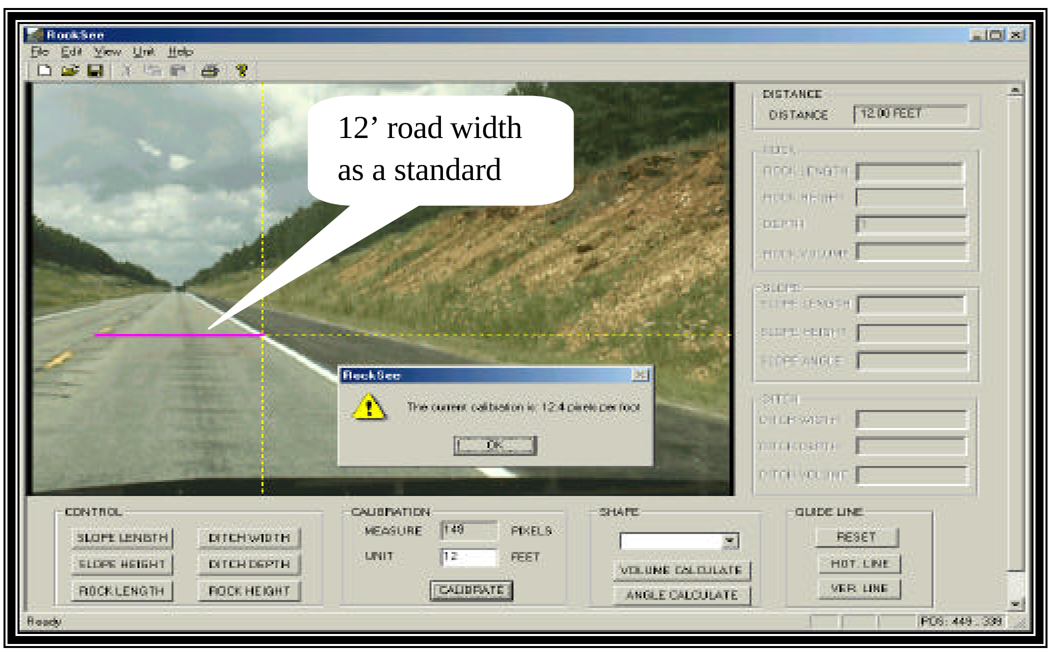


Figure 63: Top: Calibration of scale using a vertical scaling device.
(This calibration is valid only in the vertical plane defined by the horizontal dotted yellow line in any image. Bottom: Calibration of scale using road width.

5.4.6 Measurements

Measurements that can be made include slope heights, lengths, and angles; ditch widths, depths, and volumes; mass volumes; and other linear measures. Measurements all need to be made within a "measurement plane" as described below.

5.4.7 Guide and reference lines

When an image is loaded, the yellow vertical line 1/3 of the way across the image is automatically drawn in (Figure 63). The user selects the "HOT LINE" option and clicks on the intersection of the vertical yellow line and the painted white road edge line. This puts in place a horizontal dashed line that with the vertical dashed line defines the measurement plane (Figure 63). Figure 64 defines the measuring concept.

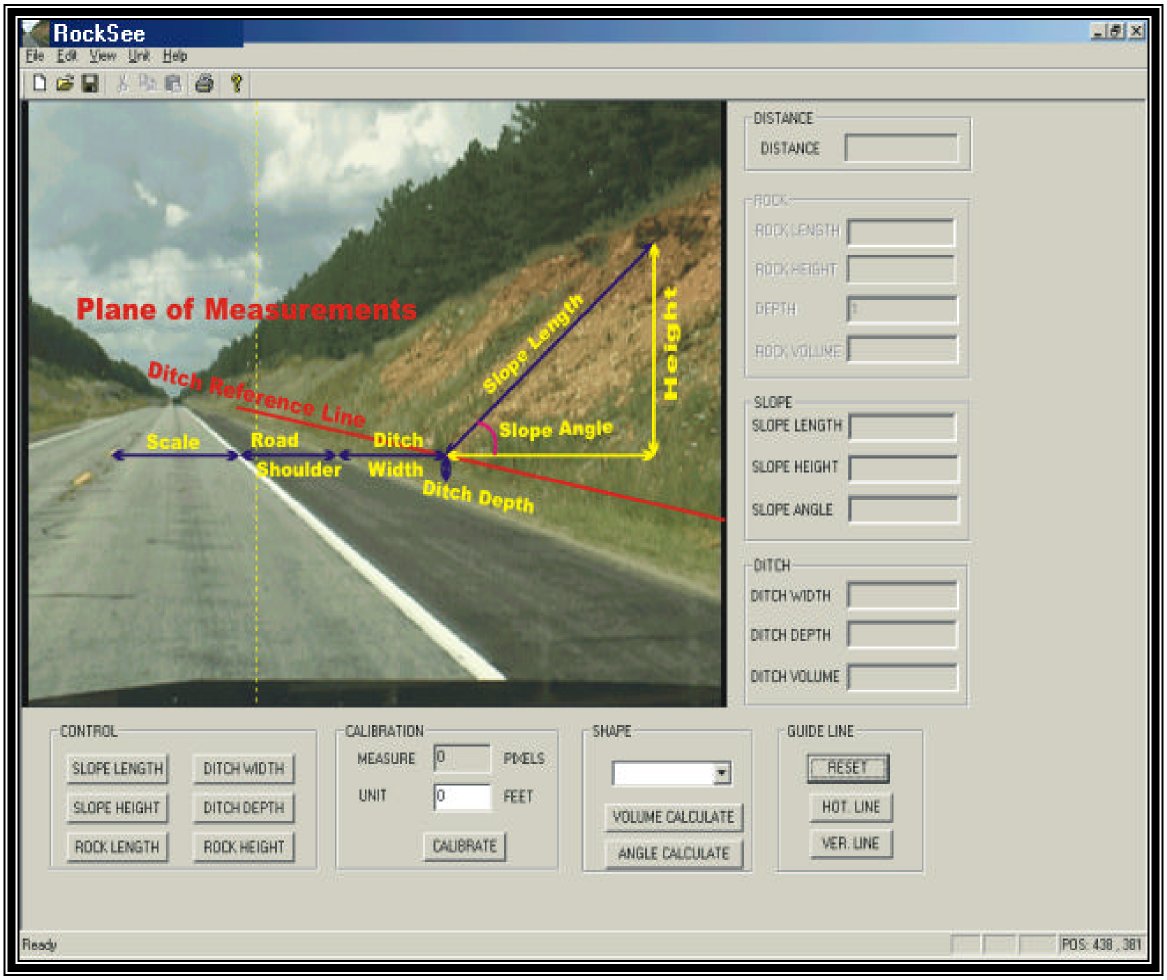


Figure 64: Plane of measurement concept.

At any time the user can select the "VER. LINE" option and put an additional vertical line in the measurement plane, for instance to define the edge of a rock face. If the ditch measurements or slope heights are required, a ditch reference line to define the outside edge of the ditch.

5.4.8 Scale calibration

Scale calibration is done in one of two ways. If a scale is entered in the measurement plane as anchored by the intersection of the vertical yellow dashed line and the painted white road edge line, this scale is valid in all images as long as the plane measurement in each case is anchored on the white edge line, and the camera tilt, pan, and zoom is not changed since the calibration was entered. The scale can also be determined at different points on an image (Figure 65). It is important to note, only the scale anchored on the painted white road edge line can be carried forward to another frame.

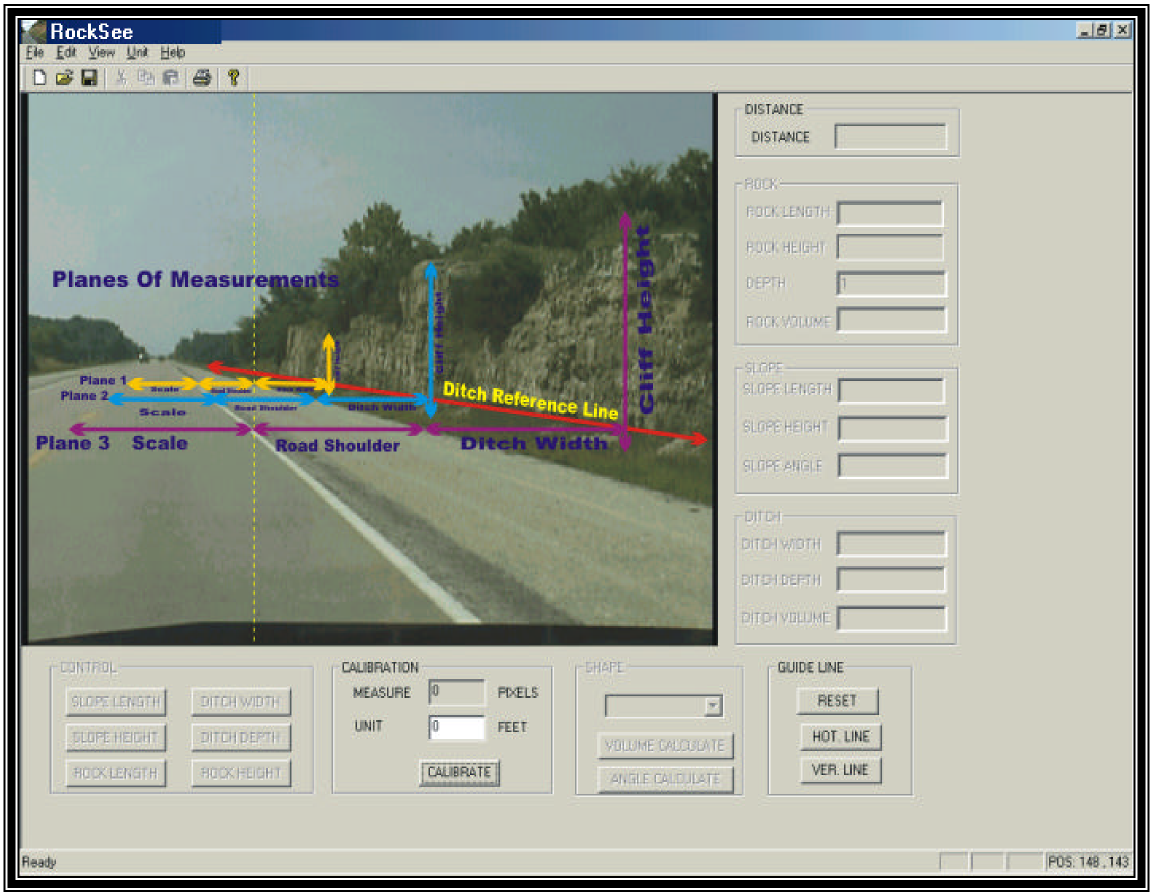


Figure 65: Multiple planes of measurement on a single image.

5.4.9 Measurements

Slope measurements (in the measurement plane) consist of measuring the height and slope face length (if not vertical) and using a trigonometric relationship to calculate the slope angle (Figure 64).

Ditch measurements (in the measurement plane) consist of measuring the width and the depth of the ditch (Figure 65). Ditch volumes per linear foot are calculated by using one of three models for calculating the cross sectional area of the ditch: Rectangle, triangle, or terrace (trapezoid).

Measurements of rock volumes, for instance volumes of loose rock, can be estimated by measuring, on a vertical slope (in the measurement plane), the height of loose blocks, and the width of loose blocks close to the proximity of the measurement plane. The depth of loose rock must be estimated, and with that the volume of loose rock can be predicted.

Any other linear measurements (in the measurement plane) can be made at any time. This includes lane and shoulder widths, and heights of objects at the side of the road, such as retaining walls.

5.4.10 Results of test measurements

A series of test measurements were conducted to evaluate the effectiveness of the measuring system.

Figure 66 shows a new modification for the RockSee program in which the AVI interface and measurement interface in one interface instead of two separate interfaces.

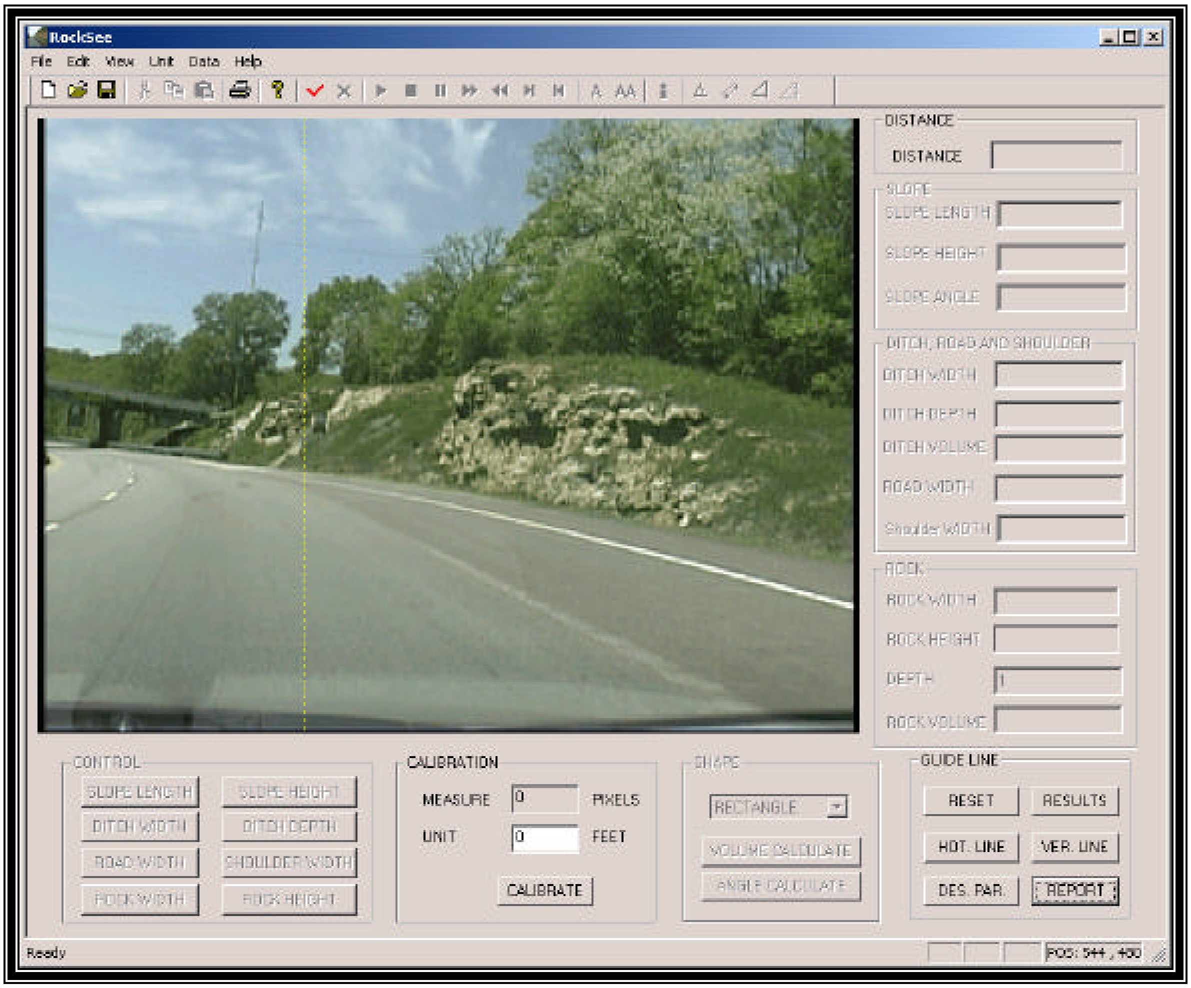


Figure 66: Modified RockSee interface

5.4.11 Manual reference measurements

To test the measuring system, 17 locations were selected along state highways, and manual measurements of measurements of road widths, ditch widths and depths, and slope heights and angles were conducted using tape measures, measuring rods, and a range-finding clinometers (Figure 67).

Figure 67: Manual measurements of road widths, ditch widths and depths, and slope heights and angles.

5.4.12 Image measurement results

Results of imaging measurements are shown in Figures 68 - 71. Errors, defined as the percentage difference between manual and image measurements, on average were found to be less than 10%. The following is the average error for each type of measurement:

Ditch Width	6.0%
Ditch Depth	8.6%
Slope Length	4.2%
Slope Angle	2.7%
Cliff Height	3.9%
Shoulder Width	7.6%
Road Width	2.7%
Rock Cut Length	4.6%

Measurements do sometimes have a high variability, with a few errors above 10%, and occasional errors of up to 30-40% when for instance miss-locating the edge or the bottom of a ditch due to the obscuring effect of vegetation.

Location		Ditch Width (m)	Ditch Depth (m)	Cliff Height (m)	Road Shoulder (m)	Road Width (m)	Comments
Site No. 1	Actual	4.26	0.61	3.65	4.26	3.65	// Image 119
	Pass 1	4.15	0.61	3.51	4.18	3.81	
	Pass 2	4.02	0.58	3.54	4.11	3.69	
	Pass 3	4.20	0.60	3.60	4.21	3.70	
	Ave.	4.12	0.60	3.55	4.17	3.73	
	Error %	3.28	1.64	2.74	2.11	2.19	// Image 119
Site No. 1	Actual	4.78	0.52	5.79	4.87	3.65	//Image 75
	Pass 1	4.84	0.58	5.88	3.69	3.35	
	Pass 2	4.90	0.51	5.85	3.60	3.51	
	Pass 3	4.78	0.53	6.10	3.81	3.60	
	Ave.	4.84	0.54	5.94	3.70	3.49	
	Error %	1.25	3.84	2.59	24.02	4.38	
Site No. 1	Actual	4.87	0.67	3.65	3.65	3.65	// Image 15 Calibration 14.2 Pixel/foot
	Pass 1	5.24	0.64	3.44	3.29	3.75	
	Pass 2	4.87	0.64	3.35	3.50	3.65	
	Pass 3	5.15	0.64	3.44	3.63	3.51	
	Ave.	5.08	0.64	3.41	3.47	3.64	
	Error %	4.31	4.47	6.57	4.93	0.27	
Site No. 1	Actual	4.57	0.46	6.10	4.42	3.65	// Image 159
	Pass 1	5.04	0.61	5.24	3.35	3.41	
	Pass 2	4.87	0.64	5.73	3.65	3.51	
	Pass 3	4.75	0.65	5.42	3.75	3.47	
	Ave.	4.89	0.63	5.46	3.58	3.46	
	Error %	7.00	36.95	10.49	19.00	5.20	
Site No. 1	Actual	4.26	0.55	5.49	4.42	3.65	//Image 214
	Pass 1	4.18	0.54	5.52	4.81	3.69	
	Pass 2	4.08	0.49	5.73	4.24	3.78	
	Pass 3	4.14	0.58	5.61	4.51	3.65	
	Ave.	4.26	0.54	5.62	4.52	3.71	
	Error %	0.00	1.81	2.36	2.26	1.64	

Figure 68: Test results #1, for errors using RockSee.

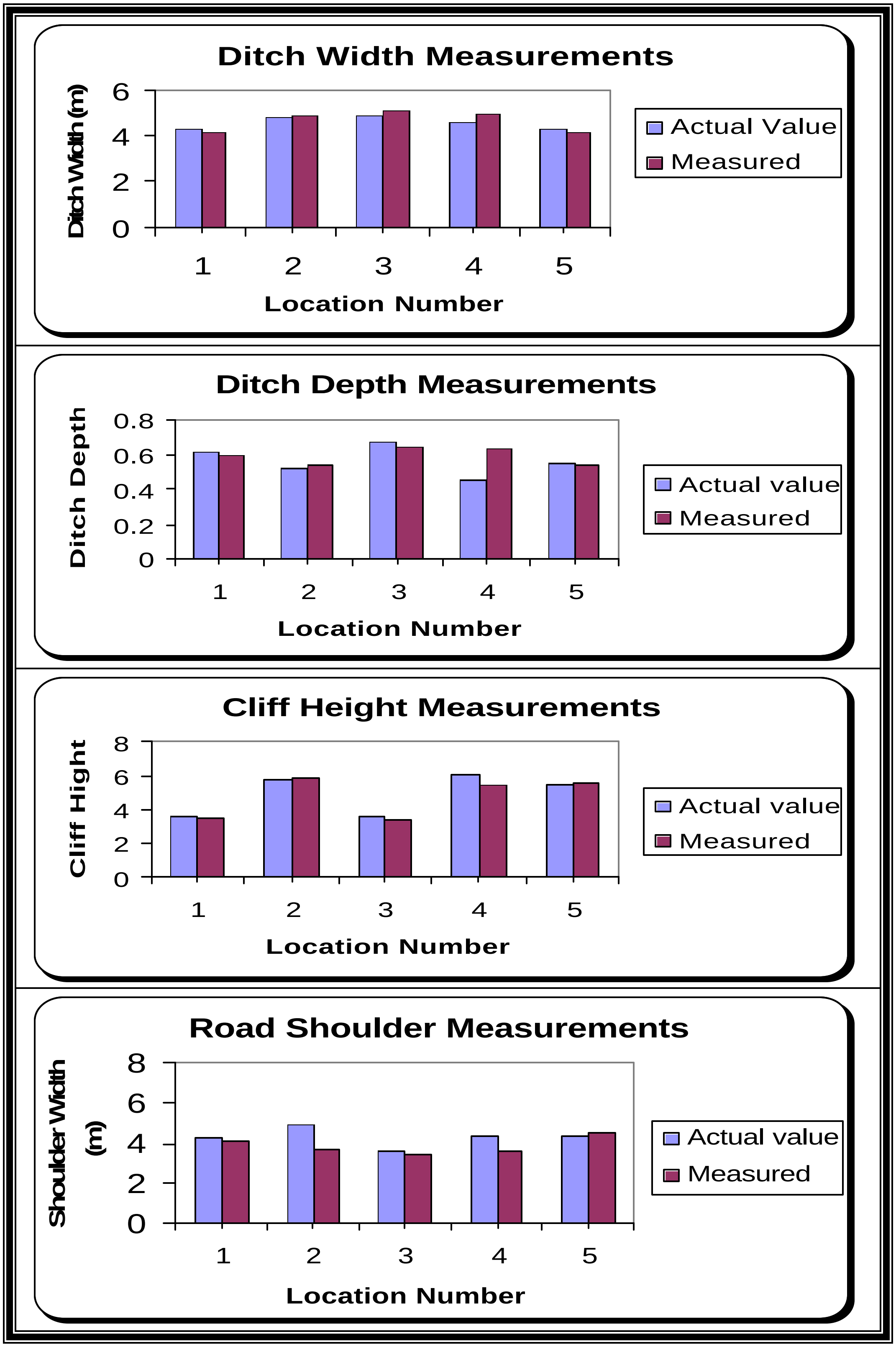


Figure 69: Error result #1, for errors using RockSee: graphs.

Location		Ditch Width (m)	Ditch Depth (m)	Slope Length (m)	Slope Angle (Degree)	Cliff Height (m)	Shoulder (m)	Comments
Site No. 1	Actual	3.96	0.49	7.01	65	N/A	3.05	//Image 18
	Pass 1	3.94	0.67	6.82	67.5	N/A	3.38	
	Pass 2	3.60	0.55	6.54	65.7	N/A	3.21	
	Pass 3	4.00	0.58	7.00	65.8	N/A	3.60	
	Ave.	3.85	0.60	6.79	66.3	N/A	3.40	
	Error %	2.77	22.44	3.13	2	-	11.47	
Site No. 2	Actual	1.98	0.46	N/A	N/A	6.40	3.05	//Image 57, 14 pixels/foot
	Pass 1	2.04	0.44	N/A	N/A	6.51	2.90	
	Pass 2	2.12	0.48	N/A	N/A	6.39	2.97	
	Pass 3	2.00	0.52	N/A	N/A	6.61	3.02	
	Ave.	2.05	0.48	N/A	N/A	6.50	2.96	
	Error %	3.53	4.34	-	-	1.56	2.95	
Site No. 3	Actual	2.29	0.46	N/A	N/A	3.96	3.14	// Image 92, 17.2 pixels/foot
	Pass 1	2.40	0.48	N/A	N/A	4.13	3.02	
	Pass 2	2.43	0.44	N/A	N/A	4.21	3.03	
	Pass 3	2.28	0.46	N/A	N/A	4.15	3.00	
	Ave.	2.37	0.46	N/A	N/A	4.16	3.02	
	Error %	3.49	0.00	-	-	5.05	3.82	
Site No. 4	Actual	2.59	0.30	8.84	42.0	N/A	3.35	// Image 129, 10.8 pixels/foot
	Pass 1	2.66	0.34	8.79	44.7	N/A	2.95	
	Pass 2	2.58	0.36	9.60	45.0	N/A	2.98	
	Pass 3	2.62	0.31	9.12	44.3	N/A	3.01	
	Ave.	2.62	0.34	9.17	44.6	N/A	2.98	
	Error %	1.15	13.33	3.73	6.19	-	11.04	
Site No. 5	Actual	2.74	0.30	6.40	40	N/A	3.20	//Image 181, 11.8 pixels/foot
	Pass 1	2.67	0.36	6.34	39.3	N/A	3.09	
	Pass 2	2.46	0.35	6.45	39.7	N/A	3.09	
	Pass 3	2.64	0.32	6.37	39.4	N/A	3.13	
	Ave.	2.59	0.34	6.39	39.4	N/A	3.10	
	Error %	5.47	13.33	0.15	1.5	-	3.12	
Site No. 6	Actual	3.35	0.37	7.62	41.0	N/A	3.20	//Image 231, 11.0 pixels/foot
	Pass 1	2.97	0.39	7.37	40.3	N/A	2.72	
	Pass 2	3.12	0.41	7.45	41.3	N/A	2.98	
	Pass 3	3.02	0.37	7.39	40.7	N/A	3.13	
	Ave.	3.04	0.39	7.40	40.8	N/A	2.94	
	Error %	9.25	5.40	2.88	0.48	-	8.12	

Figure 70: Test results #2, for errors using RockSee.

Location		Ditch Width (m)	Ditch Depth (m)	Slope Length (m)	Slope Angle (Degree)	Cliff Height (m)	Shoulder (m)	Commets
Site No. 7	Actual	3.05	0.46	4.88	45.0	N/A	3.05	// Image 274, 14.2 pixels/foot
	Pass 1	2.25	0.50	4.22	43.4	N/A	2.98	
	Pass 2	2.35	0.47	4.43	44.2	N/A	3.04	
	Pass 3	2.46	0.52	4.54	43.7	N/A	3.11	
	Ave.	2.35	0.49	4.40	43.8	N/A	3.04	
	Error %	22.9	6.52	9.83	2.66	-	0.32	
Site No. 8	Actual	2.13	0.61	N/A	N/A	3.65	3.35	//Image 308, 16.9 pixels/foot
	Pass 1	2.39	0.63	N/A	N/A	3.92	3.10	
	Pass 2	2.42	0.66	N/A	N/A	3.82	3.05	
	Pass 3	2.36	0.64	N/A	N/A	3.76	3.14	
	Ave.	2.39	0.64	N/A	N/A	3.83	3.10	
	Error %	12.20	4.91	-	-	4.93	7.46	
Site No. 9	Actual	2.13	0.52	N/A	N/A	7.01	3.35	// Image 360, 13.5 pixels/foot
	Pass 1	2.35	0.52	N/A	N/A	6.39	3.05	
	Pass 2	2.29	0.52	N/A	N/A	6.33	3.15	
	Pass 3	2.27	0.51	N/A	N/A	6.41	3.12	
	Ave.	2.30	0.52	N/A	N/A	6.38	3.11	
	Error %	7.98	0.00	-	-	8.98	7.16	
Site No.10	Actual	1.98	0.61	N/A	N/A	6.25	3.50	// Image 408, 14.5 pixels/foot
	Pass 1	2.02	0.63	N/A	N/A	6.24	3.00	
	Pass 2	2.12	0.66	N/A	N/A	6.20	3.12	
	Pass 3	2.00	0.61	N/A	N/A	6.21	3.07	
	Ave.	2.05	0.63	N/A	N/A	6.22	3.06	
	Error %	3.53	3.27	-	-	0.48	12.5	
Site No. 11	Actual	2.44	0.61	N/A	N/A	5.64	3.05	//Image 452, 14.9 pixels/foot
	Pass 1	2.65	0.63	N/A	N/A	5.29	2.96	
	Pass 2	2.61	0.63	N/A	N/A	5.64	3.05	
	Pass 3	2.41	0.60	N/A	N/A	5.42	2.94	
	Ave.	2.56	0.62	N/A	N/A	5.45	2.98	
	Error %	4.91	1.63	-	-	3.36	2.29	
Site No. 12	Actual	2.29	0.76	N/A	N/A	9.15	3.35	// Image 483, 11.0 pixels/foot
	Pass 1	2.12	0.64	N/A	N/A	8.64	3.21	
	Pass 2	2.17	0.66	N/A	N/A	8.68	3.09	
	Pass 3	2.21	0.71	N/A	N/A	8.58	3.14	
	Ave.	2.17	0.67	N/A	N/A	8.63	3.15	
	Error %	5.24	11.84	-	-	5.68	5.97	

Figure 70: (Continued)

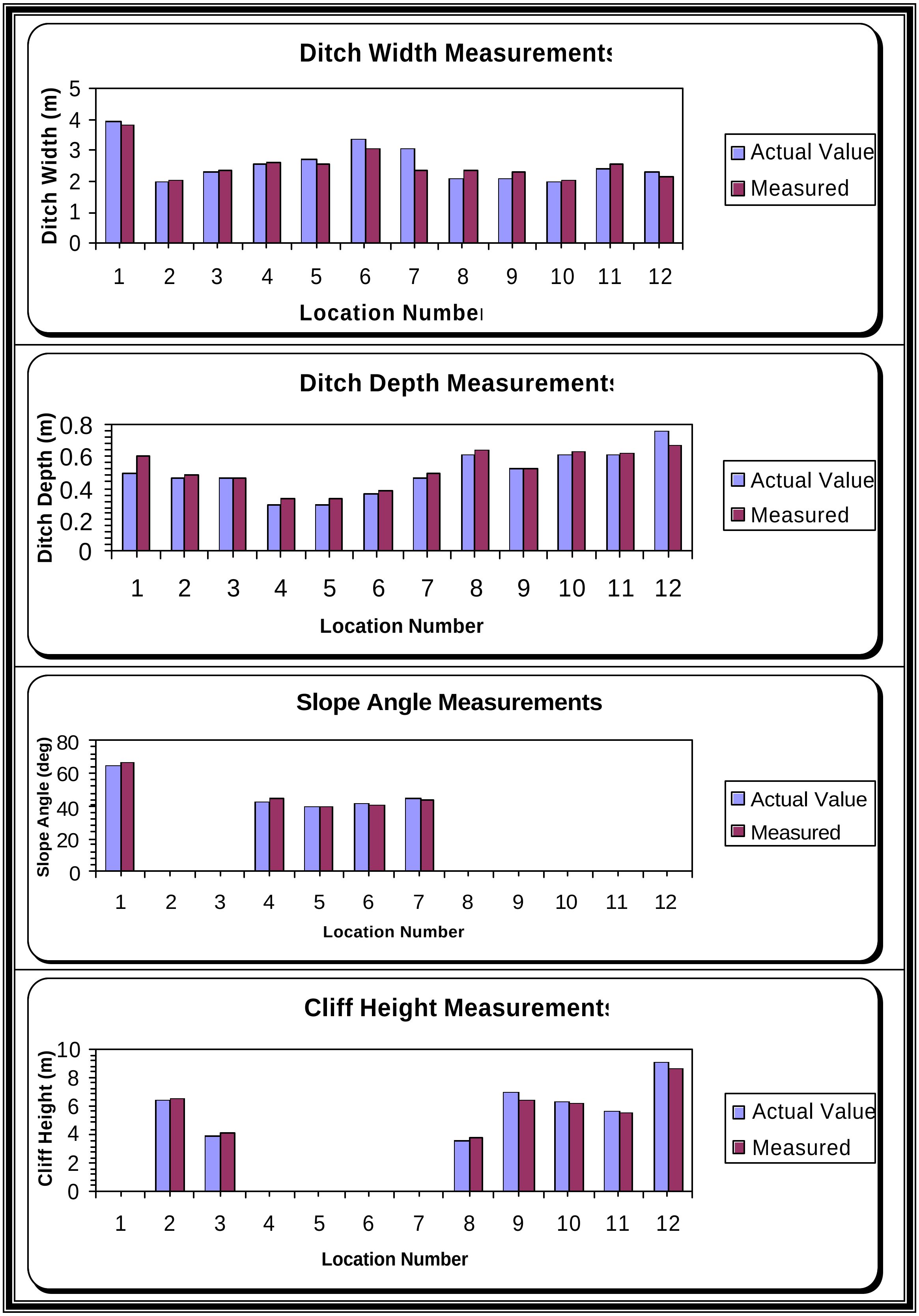


Figure 71: Error result #2, for errors using RockSee: graphs.

5.5 Results of analyses of selected Missouri highways

5.5.1 Highway 63 from Licking to Columbia Missouri)

Figures 72 and 73 show the results for 101 sites that have been studied along Highway 63. The distribution of the data shows that the data fall in three zones: high risk-high consequence, high risk-low consequence, and low risk-low consequence. Significantly there are many in the high risk-high consequence section and relatively few in the low risk-low consequence section. Figure 74 and 75 show examples of a rock cuts along Highway 63.

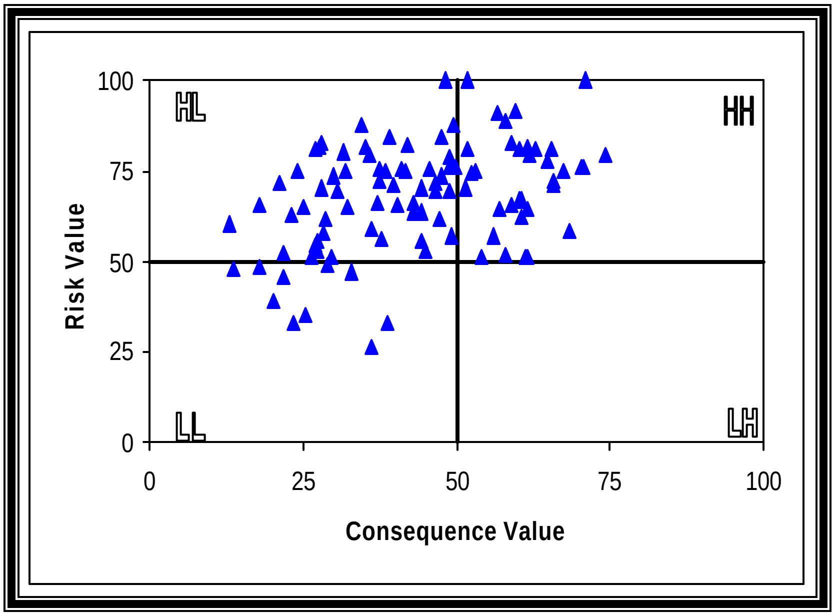


Figure 72: Risk – Consequence diagram for the (quadrant) data from Highway 63. LL = Low Risk Low Consequence, HL = High Risk Low Consequence, HH = High Risk, High Consequence, and LH = Low Risk High Consequence

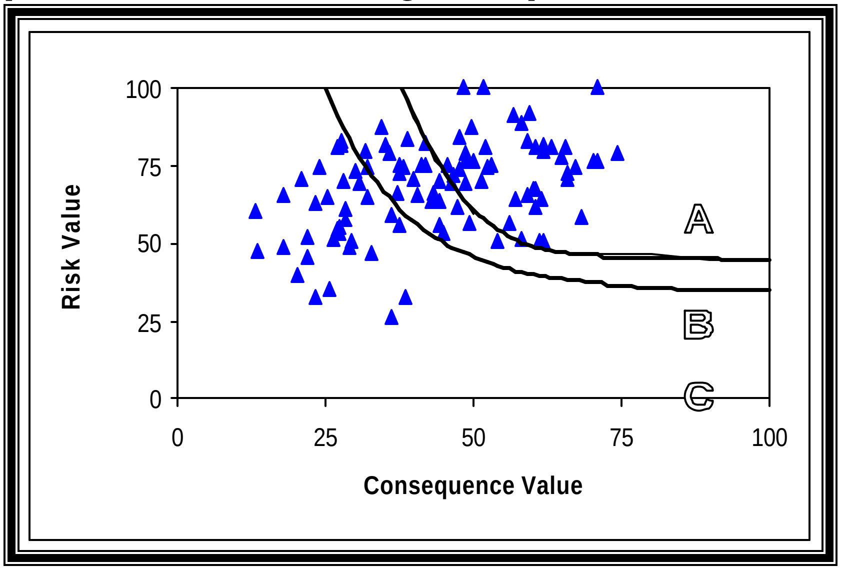


Figure 73: Risk – Consequence diagram for the (zoned) data from Highway 63. A= Highly Hazardous Zone, B = Moderately Hazardous Zone, and C = Good Zone

HYW	Elevation	Latitude	Longitude
63	799 ft	N 38-08.974	W 091-53.517

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	45		9	Ditch Width	13		1.6
Slope Angle	90		12	Ditch Volume	13		6.8
Rockfall History	4		12	Slope Angle	90		0
Weathering	4		24	Shoulder Width	16		0
Rock Strength	0		12	Lanes Number	1		12
Face Irregularities	4		12	Average daily Traffic	5500		3.3
Face Looseness	4		12	Rockfall Quantity	100		12
Block Size	5		0	Average Vehicle Risk	65	500	4.0
Water on Face	1		3	Design Sight Dist.	0		0
	Joint	Sinkh.		Block Size	5		12
Adjust. Factor	0	3	9	Adjust. Factor	7.7		15.0
Total			89	Total			58.1

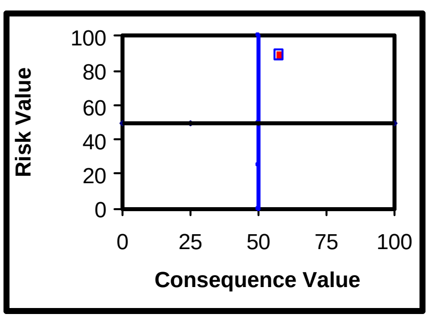


Figure 74: Report for site No. 58 on Highway 63.

Site No.	HYW	Elevation	Latitude	Longitude
87	63	738 ft	N 38- 40.267	W 092-14.073

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	25		5	Ditch Width	17		0
Slope Angle	90		12	Ditch Volume	25		2
Rockfall History	4		12	Slope Angle	90		0
Weathering	4		24	Shoulder Width	10		2
Rock Strength	1		9	Lanes Number	2		6
Face Irregularities	4		12	Average daily Traffic	17000		10.2
Face Looseness	4		12	Rockfall Quantity	100		12
Block Size	4		1	Average Vehicle Risk	70	350	4.0
Water on Face	1		3	Design Sight Dist.	0		0
	Joint	Sinkh.		Block Size	4		8
Adjust. Factor	**0**	2	6	**Adjust. Factor**	4.0		15.0
Total			**80.6**	**Total**			**51.9**

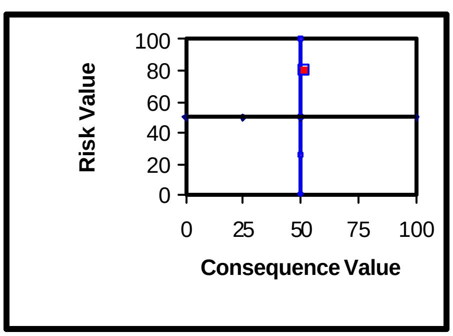


Figure 75: Report for site no. 87 on Highway 63.

5.5.2 Highway 44 between St. Louis and Springfield

Figures 76 and 77 show the results for 70 sites that had been studied along Highway 44. The distribution of the data shows that the data fall in three zones: high risk-high consequence, high risk-low consequence, and low risk-low consequence. Significantly there are many in the high risk-high consequence section and relatively few in the low risk-low consequence section. Figures 78 and 79 show examples of a rock cuts along Highway I-44 from St. Louis to Springfield west and east of Rolla MO.

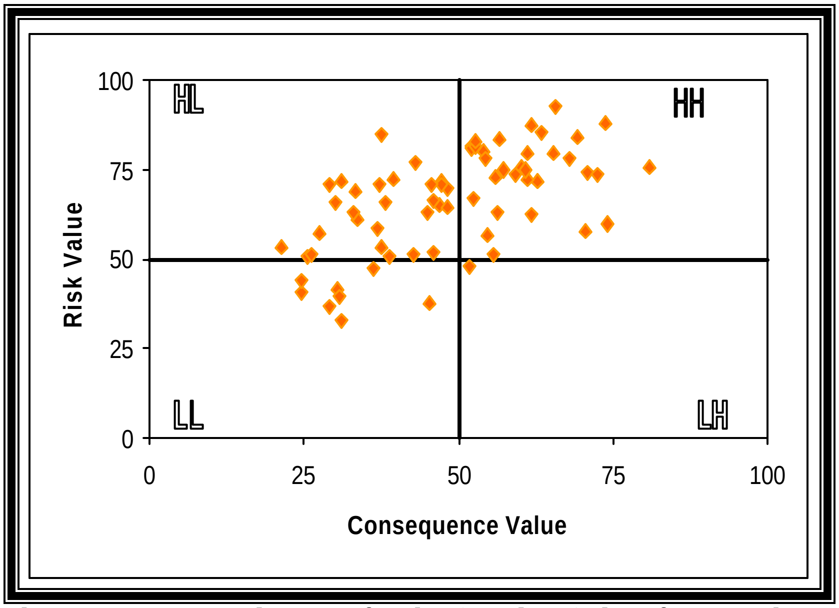


Figure 76: Risk – Consequence diagram for the (quadrant) data from Highway 44.
LL = Low Risk Low Consequence, HL = High Risk Low Consequence, HH = High Risk, High Consequence, and LH = Low Risk High Consequence

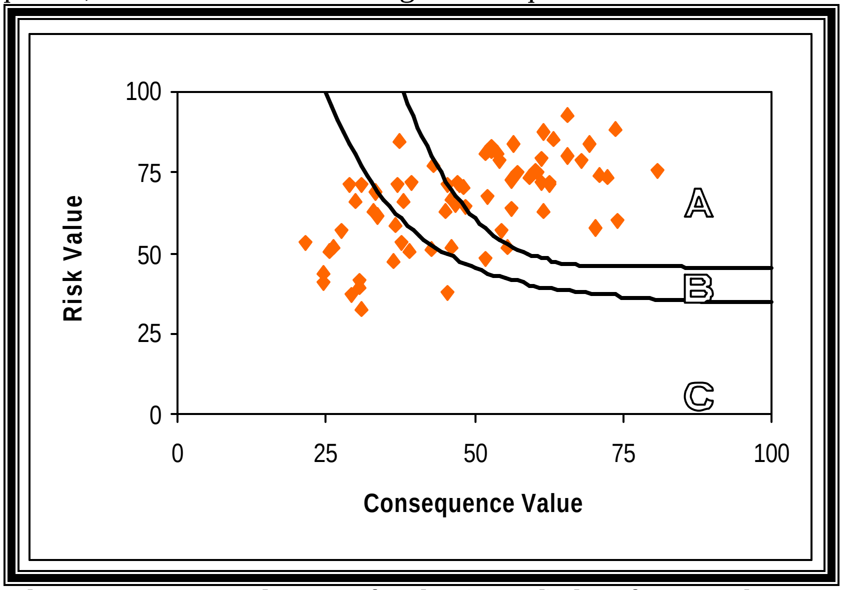


Figure 77: Risk – Consequence diagram for the (zoned) data from Highway 44.
A= Highly Hazardous Zone, B = Moderately Hazardous Zone, and C = Good Zone

Site No.	HYW	Elevation	Latitude	Longitude
27	44	917 ft	N 37- 51.762	W 092-03.158

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	20		4	Ditch Width	18		0
Slope Angle	90		12	Ditch Volume	33		0
Rockfall History	1		3	Slope Angle	90		0
Weathering	1		6	Shoulder Width	11		1
Rock Strength	3.5		1.5	Lanes Number	2		6
Face Irregularities	1		3	Average daily Traffic	24000		12
Face Looseness	1.5		4.5	Rockfall Quantity	5		1.5
Block Size	4		1	Average Vehicle Risk	70	500	8.1
Water on Face	3		9	Design Sight Dist.	0		0
	Joint	Sinkh.		Block Size	4		8
Adjust. Factor	**0**	1	3	**Adjust. Factor**	1.0		0.0
Total			**39.2**	**Total**			**30.6**

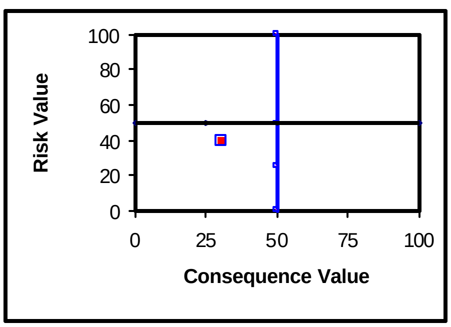


Figure 78: Report for site no. 27 on Highway I-44.

Site No.	HYW	Elevation	Latitude	Longitude
70	44	1000 ft	N 38- 29.185	W 090-46.050

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	45		9	Ditch Width	20		4
Slope Angle	85		11	Ditch Shape	2		8
Rockfall History	4		12	Ditch Volume	20		4
Weathering	4		24	Slope Angle	85		12
Rock Strength	0.5		10.5	Shoulder Width	12		0
Face Irregularities	4		12	Lanes Number	2		6
Face Looseness	4		12	Average daily Traffic	24000		12
Block Size	2.5		3	Rockfall Quantity	150		12
Water on Face	0		0	Average Vehicle Risk	70	400	6.5
	Joint	Sinkh.		Design Sight Dist.	1		4
Adjust. Factor	**0**	2	6	Block Size	2.5		3
Total			**84**	**Adjust. Factor**	7.5		15.0
				Total			**69.4**

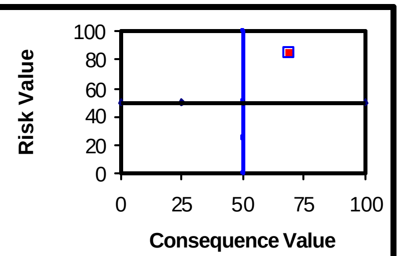


Figure 79: Report for site no. 70 on Highway I-44.

5.5.3 Highway 65 between Springfield and Branson

Figures 80 and 81 show the results for 60 sites that had been studied along Highway 65. The distribution of the data shows that the data falls in three zones: high risk-high consequence, high risk-low consequence, and low risk-low consequence. Significantly there are many in the low risk-low consequence section and relatively few in the high risk-high consequence section. Figures 82 and 83 show some examples of a rock cuts along Highway 65 between Springfield and Branson MO.

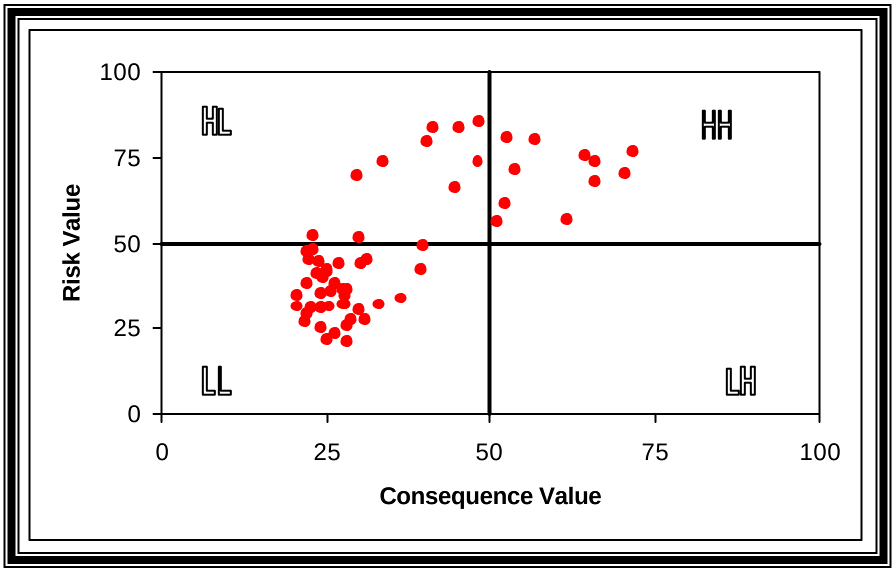


Figure 80: Risk – Consequence diagram for the (quadrant) data from Highway 65.
LL = Low Risk Low Consequence, HL = High Risk Low Consequence, HH = High Risk, High Consequence, and LH = Low Risk High Consequence

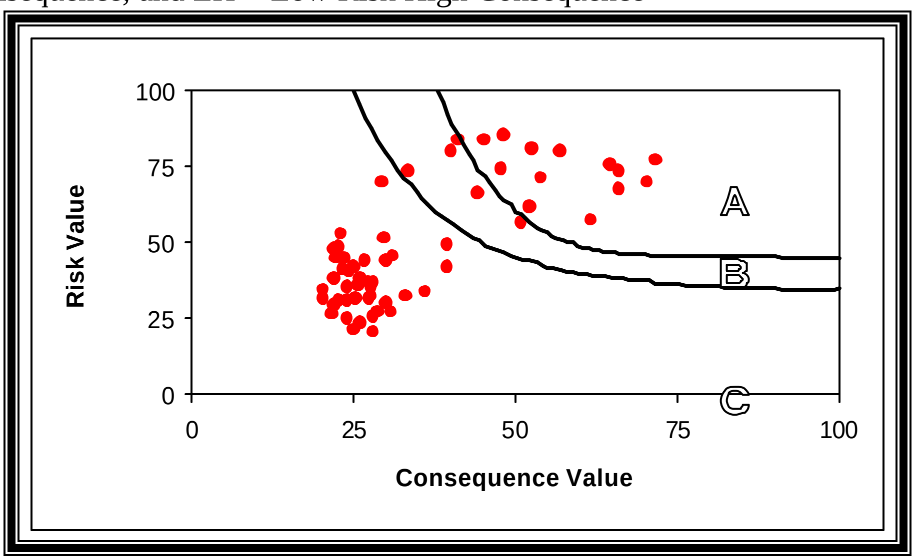


Figure 81: Risk – Consequence diagram for the (zoned) data from Highway 65.
A= Highly Hazardous Zone, B = Moderately Hazardous Zone, and C = Good Zone

Site No.	HYW	Elevation	Latitude	Longitude
8	65	1119 ft	N 36- 52.086	W 093-13.772

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	25		5	Ditch Width	7		6.4
Slope Angle	90		12	Ditch Volume	7		9.2
Rockfall History	4		12	Slope Angle	90		0
Weathering	3.5		21	Shoulder Width	10		2
Rock Strength	1.5		7.5	Lanes Number	2		6
Face Irregularities	3		9	Average daily Traffic	24000		12
Face Looseness	3		9	Rockfall Quantity	40		12
Block Size	5		0	Average Vehicle Risk	65	500	8.7
Water on Face	2		6	Design Sight Dist.	0		0
	Joint	Sinkh.		Block Size	5		12
Adjust. Factor	**0**	3	9	**Adjust. Factor**	5.7		15.0
Total			**77**	**Total**			**71.9**

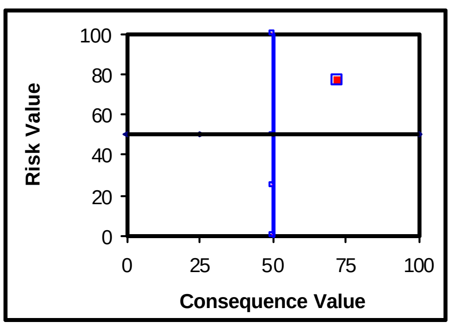


Figure 82: Report for site no. 8 on Highway 65.

Site No.	HYW	Elevation	Latitude	Longitude
42	65	906 ft	N 36-40.376	W 093-13.256

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	35		7	Ditch Width	15		6
Slope Angle	90		12	Ditch Shape	1.5		6
Rockfall History	0.5		1.5	Ditch Volume	20		4
Weathering	0.5		3	Slope Angle	90		0
Rock Strength	3.5		1.5	Shoulder Width	15		0
Face Irregularities	1		3	Lanes Number	2		6
Face Looseness	2		6	Average daily Traffic	24000		12
Block Size	5		0	Rockfall Quantity	5		1.5
Water on Face	1		3	Average Vehicle Risk	65	25	0.4
	Joint	Sinkh.		Design Sight Dist.	0		0
Adjust. Factor	**0**	1	3	Block Size	5		12
Total			**33.9**	**Adjust. Factor**	1.0		0.0
				Total			**36.3**

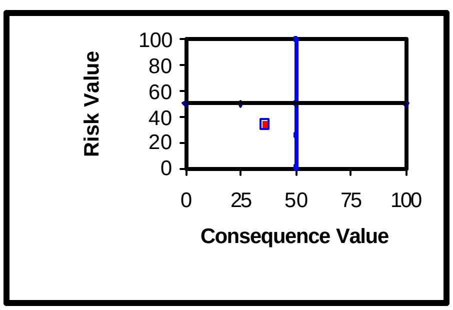


Figure 83: Report for site no. 42 on Highway 65.

5.5.4 Highway 54

Figures 84 and 85 show the results for 30 sites that had been studied along highway 54. The distribution of the data shows that the data fall in three zones: high risk-high consequence, high risk-low consequence, and low risk-low consequence. Significantly there are many in the high risk-low consequence section and relatively few in the high risk-high consequence section. Figures 86 and 87 show some examples of two rock cuts along Highway 54.

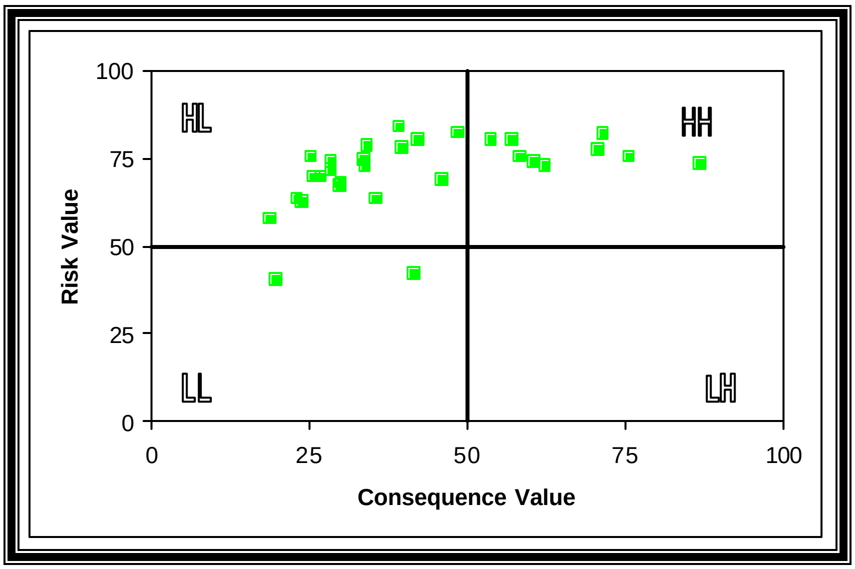


Figure 84: Risk – Consequence diagram for the (quadrant) data from Highway 54. LL = Low Risk Low Consequence, HL = High Risk Low Consequence, HH = High Risk, High Consequence, and LH = Low Risk High Consequence

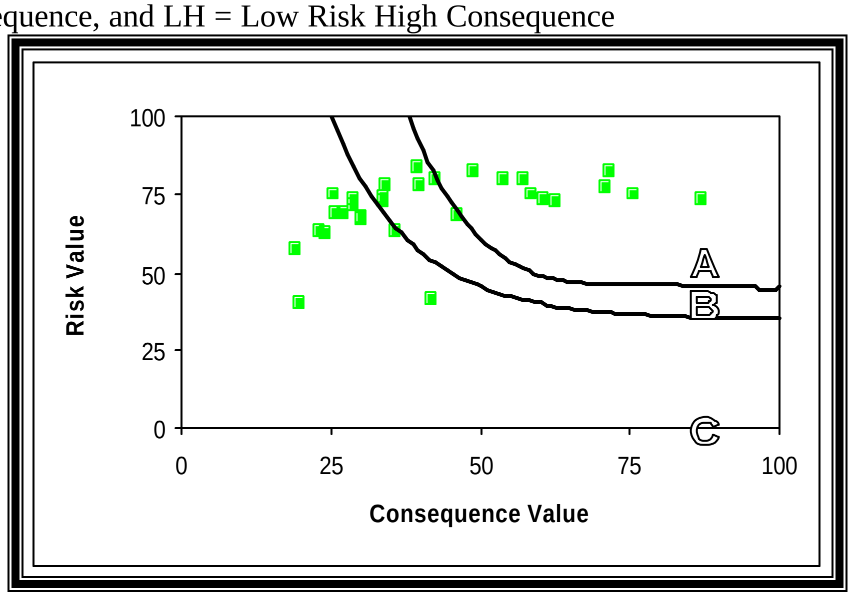


Figure 85: Risk – Consequence diagram for the (zoned) data from Highway 54.

A= Highly Hazardous Zone, B = Moderately Hazardous Zone, and C = Good Zone

Site No.	HYW	Elevation	Latitude	Longitude
3	54	764 ft	N 38-13.423	W 092-37.527

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	40		8	Ditch Width	25		2
Slope Angle	75		9	Ditch Shape	0		0
Rockfall History	2		6	Ditch Volume	40		0
Weathering	2.5		15	Slope Angle	75		5
Rock Strength	2		6	Shoulder Width	13		0
Face Irregularities	2		6	Lanes Number	2		6
Face Looseness	3		9	Average daily Traffic	13000		7.8
Block Size	2		5	Rockfall Quantity	5		1.5
Water on Face	3		9	Average Vehicle Risk	70	300	2.6
	Joint	Sinkh.		Design Sight Dist.	1		4
Adjust. Factor	0	1	3	Block Size	2		2
Total			63.4	Adjust. Factor	1.0		0.0
				Total			23.5

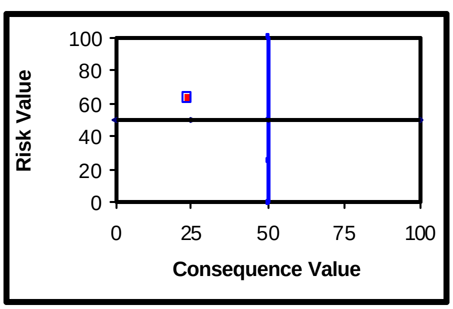


Figure 86: Report for site no. 3 on Highway 54.

Site No.	HYW	Elevation	Latitude	Longitude
14	54	661 ft	N 38-31.359	W 092-13.742

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	35		7	Ditch Width	2		11.2
Slope Angle	80		10	Ditch Shape	2.5		10
Rockfall History	4		12	Ditch Volume	1		11.6
Weathering	3		18	Slope Angle	80		9
Rock Strength	1.5		7.5	Shoulder Width	13		0
Face Irregularities	4		12	Lanes Number	2		6
Face Looseness	4		12	Average daily Traffic	24000		12
Block Size	5		0	Rockfall Quantity	120		12
Water on Face	2		6	Average Vehicle Risk	70	450	7.3
	Joint	Sinkh.		Design Sight Dist.	1		4
Adjust. Factor	**0**	1	3	Block Size	5		12
Total			**73.4**	**Adjust. Factor**	120.0		15.0
				Total			**87.0**

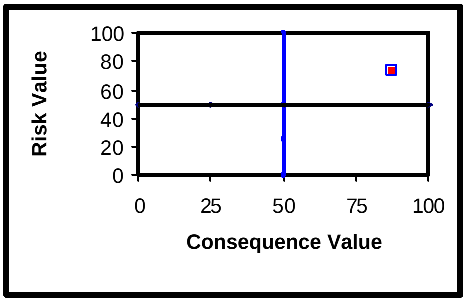


Figure 87: Report for site no. 14 on Highway 54.

5.5.5 Other highways: 30, 55, 8, 110, 61, 72, 67 and route W

Figures 88 and 89 show the results for 33 sites that had been studied along the above highways. The distribution of the data shows that the data fall in three zones: high risk-high consequence, high risk-low consequence, and low risk-low consequence with exception of one site in low risk high consequence. Significantly there are many in the high risk-low consequence section and relatively few in the high risk-high consequence section. Figure 90 and 91 show examples of two rock cuts along some sites of these Highways.

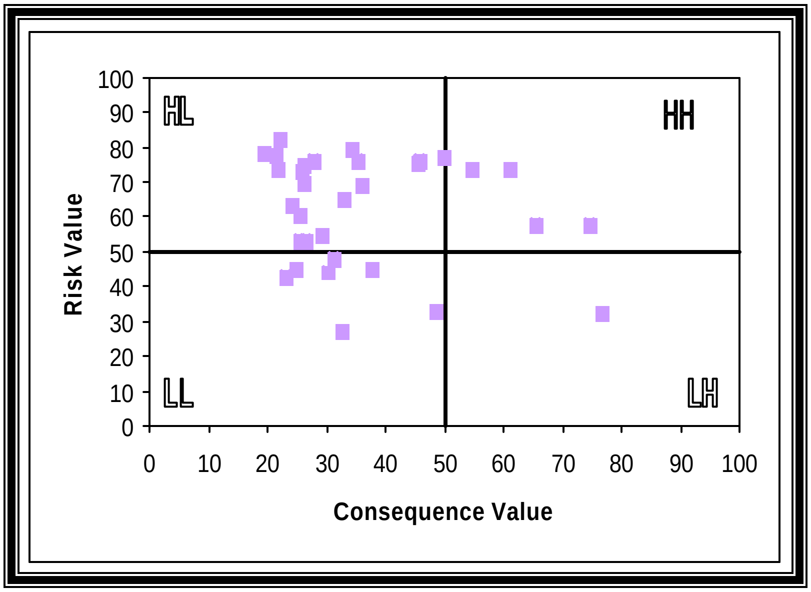


Figure 88: Risk – Consequence diagram for the (quadrant) data other highways. LL = Low Risk Low Consequence, HL = High Risk Low Consequence, HH = High Risk, High Consequence, and LH = Low Risk High Consequence

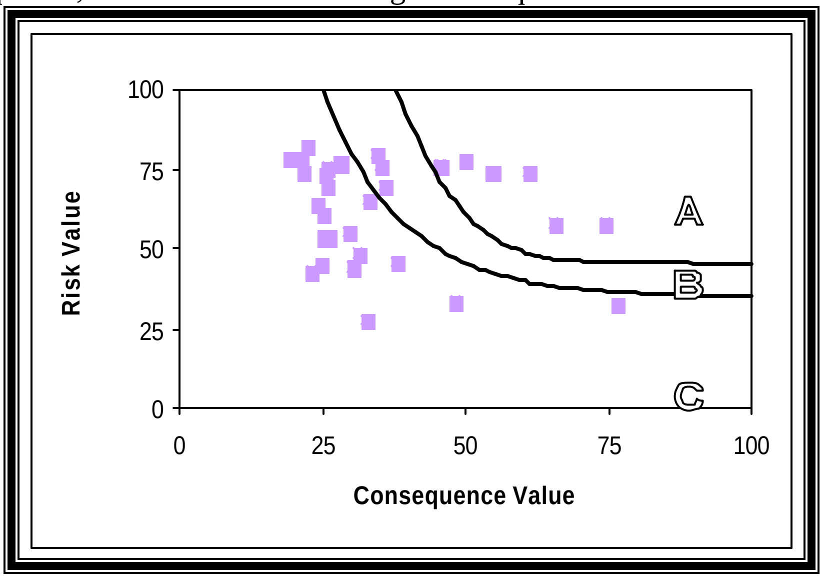


Figure 89: Risk – Consequence diagram for the (zoned) data from other highways. A= Highly Hazardous Zone, B = Moderately Hazardous Zone, and C = Good Zone

Site No.	HYW	Elevation	Latitude	Longitude
9	72	735 ft	N 37-33.982	W 090-20.978

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	30		6	Ditch Width	22		0
Slope Angle	90		12	Ditch Volume	33		0
Rockfall History	3		9	Slope Angle	90		0
Weathering	1		6	Shoulder Width	10		2
Rock Strength	4		0	Lanes Number	1		12
Face Irregularities	3		9	Average daily Traffic	2000		1.2
Face Looseness	3		9	Rockfall Quantity	40		12
Block Size	5		0	Average Vehicle Risk	60	200	0.6
Water on Face	1		3	Design Sight Dist.	0		0
	Joint	Sinkh.		Block Size	5		12
Adjust. Factor	0	0	0	Adjust. Factor	1.2		1.1
Total			45	Total			34.2

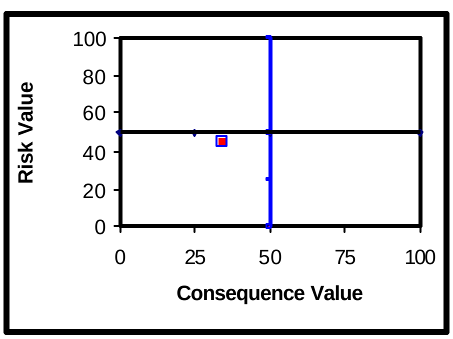


Figure 90: Report for site no. 9 on Highway 72.

Site No.	HYW	Elevation	Latitude	Longitude
30	61	1100 ft	N 38- 09.475	W 090-21.355

Risk	Value		Rating	Consequence	Value		Rating
Rock Cut Height	45		9	Ditch Width	6		9.6
Slope Angle	85		11	Ditch Shape	4		12
Rockfall History	3		9	Ditch Volume	3		10.8
Weathering	3.5		21	Slope Angle	85		12
Rock Strength	1.5		7.5	Shoulder Width	10		2
Face Irregularities	4		12	Lanes Number	1		12
Face Looseness	3		9	Average daily Traffic	5000		3
Block Size	3		2	Rockfall Quantity	20		6
Water on Face	1		3	Average Vehicle Risk	55	300	2.6
	Joint	Sinkh.		Design Sight Dist.	1		4
Adjust. Factor	**0**	0	0	Block Size	3		5
Total			**69.6**	**Adjust. Factor**	6.7		15.0
				Total			**74.6**

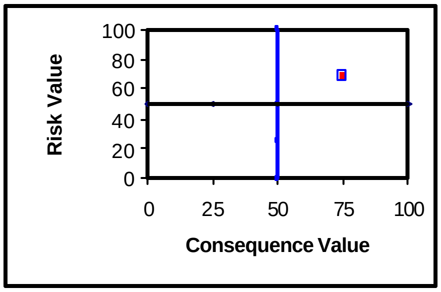


Figure 91: Report for site no. 30 on Highway 61.

5.6 System verification (multi-user trials)

Ten sites from Highway 63 between Rolla City and Jefferson City were selected (Figure 92), to analyze to see how the rating system responds to different users (rated parameters only). In all, twelve ratings were done. During the first session, Maerz, Youssef, 4 MODOT personnel, and 1 UMR graduate student rated the 10 cuts. During the second session, Maerz, Youssef, and 3 UMR graduate students rated the cuts.

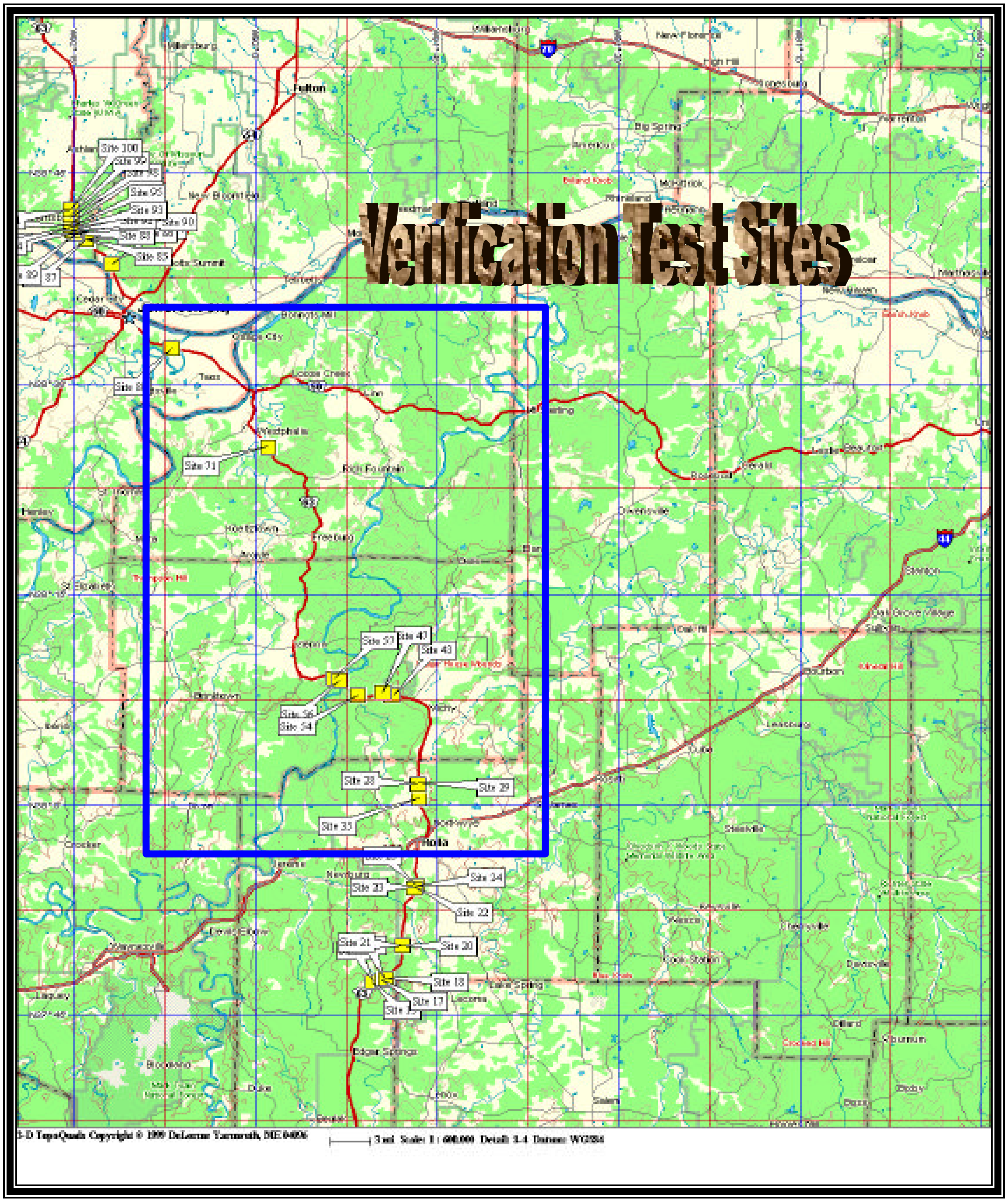


Figure 92: Site map for the cuts to be rated.

The rating data is shown in Tables 18 and 19.

Table 18: Risk rating for the 10 test sites.

Rater	Site 35	Site 28	Site 29	Site 43	Site 47	Site 54	Site 56	Site 57	Site 71	Site 80
1	45.9	54.2	69.2	36.2	90.8	52.3	64.6	68.8	58.3	65.3
2	50.9	51.7	97.5	45.8	100.0	53.8	67.5	99.2	63.3	70.3
3	40.9	49.2	94.2	31.2	97.5	57.3	70.8	94.2	58.3	69.9
4	45.0	51.7	92.5	42.9	90.9	55.5	64.7	95.4	45.8	62.4
5	42.5	50.8	94.2	48.7	100.0	59.2	70.0	100.0	65.0	74.5
6	49.6	49.2	100.0	43.7	100.0	58.5	65.0	96.3	63.3	70.7
7	48.4	52.9	100.0	46.2	100.0	57.2	67.2	100.0	63.8	72.4
8	45.9	50.8	100.0	45.8	99.2	58.8	64.2	93.3	62.5	72.0
9	50.9	52.9	100.0	42.6	94.2	58.8	70.0	96.7	58.3	71.2
10	50.9	57.1	100.0	46.7	100.0	61.3	71.2	99.2	64.6	72.0
11	50.8	51.7	100.0	46.2	95.0	61.3	69.6	95.4	62.5	69.5
12	49.7	52.9	100.0	47.6	100.0	58.5	68.4	100.0	64.6	71.6
Average	**47.6**	**52.1**	**95.6**	**43.7**	**97.3**	**57.7**	**67.8**	**94.9**	**60.9**	**70.2**

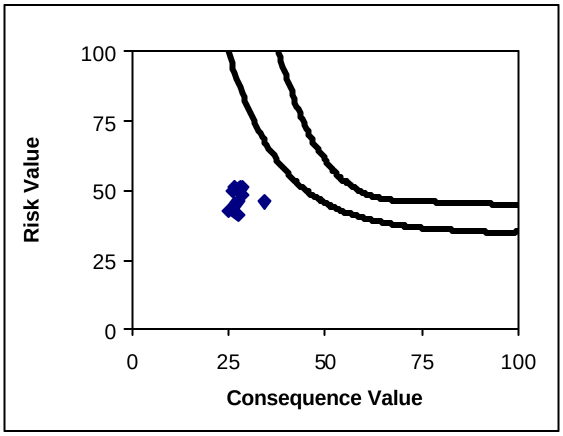
Table 19: Consequence ratings for the 10 test sites.

Rater	Site 35	Site 28	Site 29	Site 43	Site 47	Site 54	Site 56	Site 57	Site 71	Site 80
1	34.3	31.7	71.9	25.4	48.8	12.1	45.5	42.4	34.2	21.1
2	26.4	28.7	73.4	24.1	49.1	17.6	43.9	44.4	34.8	18.6
3	27.4	26.5	71.6	23.6	44.6	15.6	42.8	45.7	33.0	22.3
4	26.5	26.5	71.9	24.1	49.3	10.5	46.6	45.7	30.8	21.8
5	25.2	24.9	74.7	25.9	45.3	11.3	43.9	41.6	30.0	19.5
6	26.2	26.5	71.6	25.4	45.1	15.2	42.3	42.4	29.6	18.3
7	28.6	26.5	74.7	25.4	48.8	15.1	42.8	45.7	32.7	21.1
8	27.6	26.1	70.1	23.3	48.5	14.4	45.2	40.8	33.0	19.5
9	28.6	28.7	73.2	23.2	45.1	15.1	45.5	41.1	30.4	21.1
10	28.0	31.4	71.6	24.1	45.5	13.0	42.3	41.1	33.8	20.8
11	26.4	28.7	70.1	24.8	45.1	15.1	45.3	41.1	28.9	19.5
12	27.4	26.5	73.2	23.4	47.1	14.5	44.4	45.7	33.0	21.1
Average	**27.7**	**27.7**	**72.3**	**24.4**	**46.9**	**14.1**	**44.2**	**43.1**	**32.0**	**20.4**

The following tables and figures will show the sites that we use for verification the system.

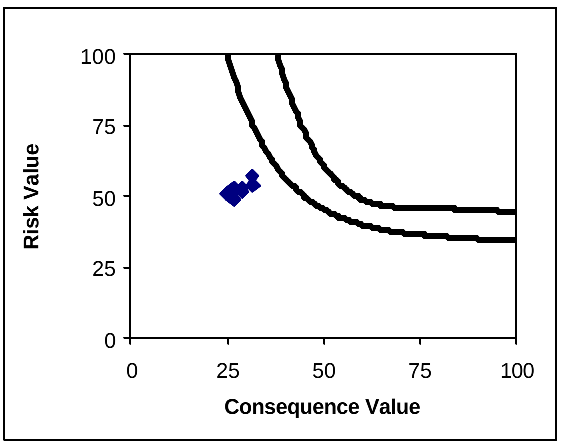
From the figures we can see that the MORFH RS is so consistent as to identify the difference between the sites that highly risk and consequence from other sites that is low risk - low consequence.

Figures 93 - 96 show the variability in the Risk Consequence plots for each site.



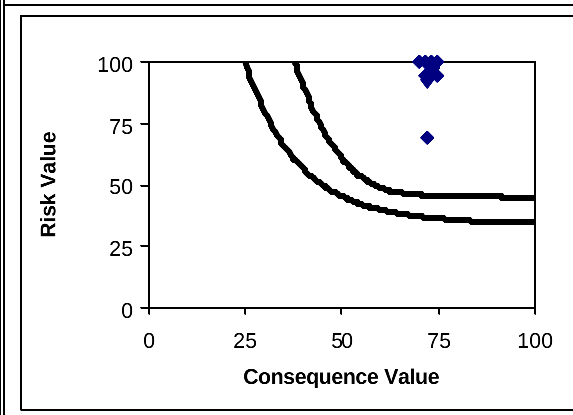
Data for Site 35

Image for Site 35



Data for Site 28

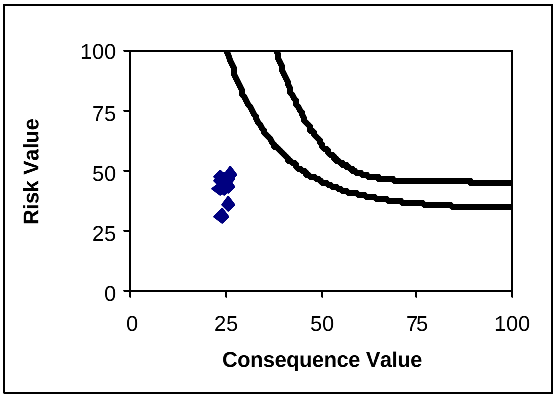
Image for Site 28



Data for Site 29

Image for Site 29

Figure 93: Risk - Consequence plots, test sites.



Data for Site 43

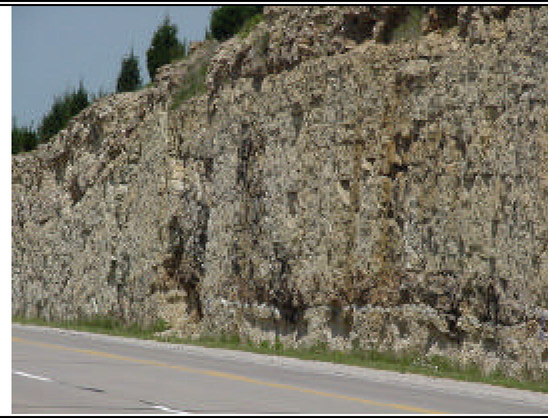
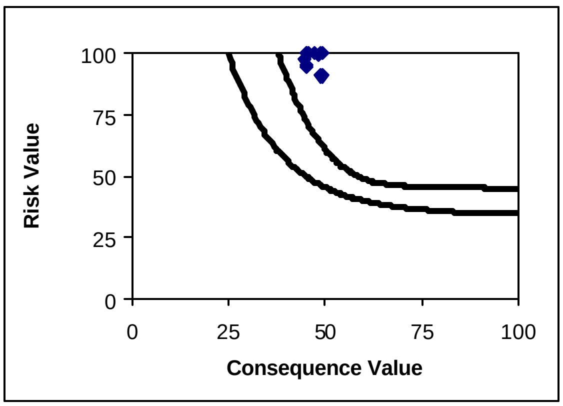
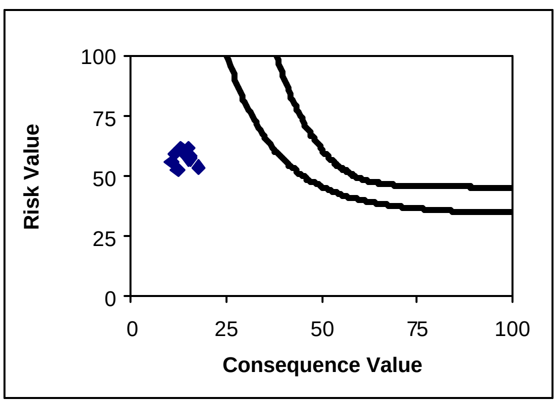


Image for Site 43



Data for Site 47

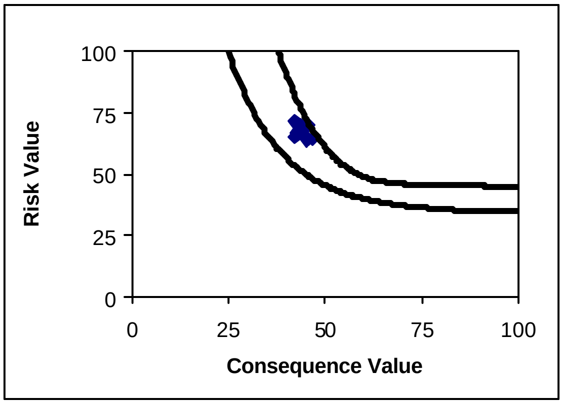
Image for Site 47



Data for Site 54

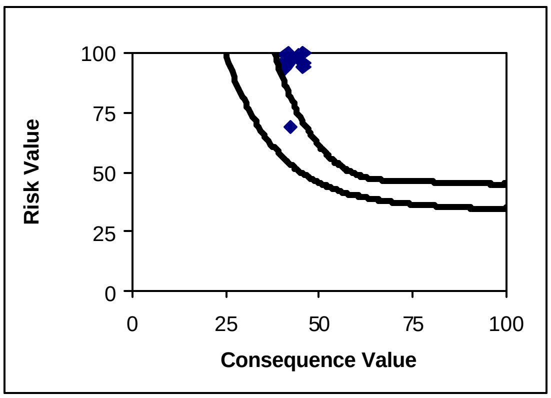
Image for Site 54

Figure 94: Risk - Consequence plots, test sites.



Data for Site 56

Image for Site 56



Data for Site 57

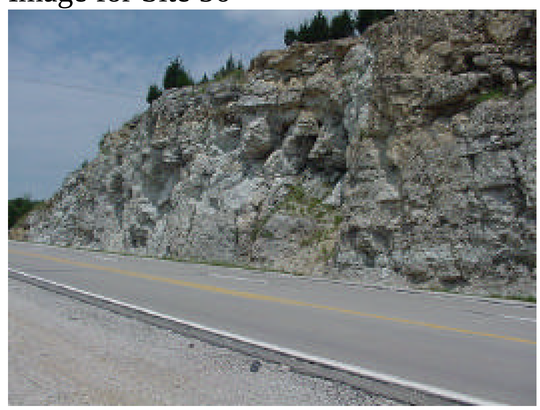
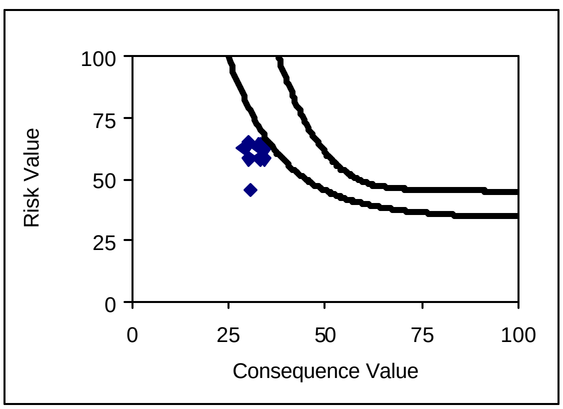


Image for Site 57



Data for Site 71

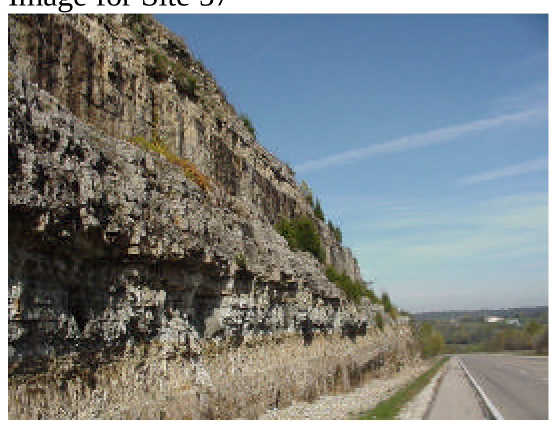
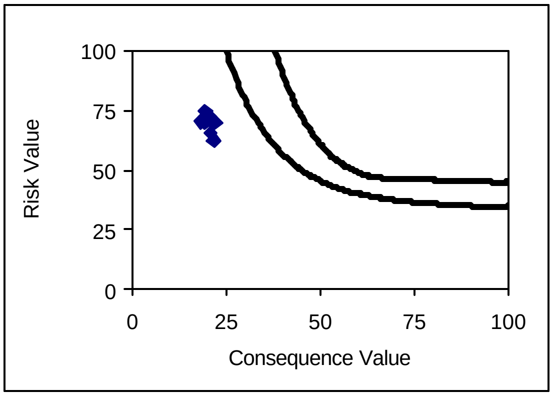


Image for Site 71

Figure 95: Risk - Consequence plots, test sites.



Data for Site 80


Image for Site 80

Figure 96: Risk - Consequence plots, test sites.

Comment on the analysis:

From the results we can see most of the data are very close but still there is a difference like 5 to 8 % for both risk and consequence for at least 1 rater. Perhaps the training time of 30 minutes was not enough to make the personnel familiar with the system and how to rate the parameters.

6. Methodology for Evaluation of the Cost Effectiveness of Repair/Remediation/ Maintenance of Rock Cuts

6.1 Introduction

MORFH RS outputs a risk and a consequence index as in Figure 93 to 96. Based this graph, prioritization of the remediation can start.

6.2 Methods to prioritize which site need to be repaired first

The cost-benefit ratio of repair/remediation/maintenance is addressed here. We will express the concept by the following proposed formulation:

$$\textbf{Cost/Benefit Index} = \frac{\textbf{? Severity Index}}{\textbf{Repair/Remediation/Maintenance Cost}}$$

Where:

$$\textbf{Severity Index} = \frac{\textbf{Risk Index + Consequence Index}}{\textbf{2}}$$

And:

? Severity Index = Severity Index (before Repair/Remediation/Maintenance) – Severity Index (after Repair/Remediation/Maintenance)

Since ? Severity Index will be a difference between two numbers between 0-100, and Cost is in $, the units of the cost benefit index can be thought of as the ***% point change (decrease) in the combined Risk and Consequence per dollar of effort.***

This is a very simple calculation that is designed to give some relative indication of the values of Repair/Mediation/Maintenance actions.

6.3 Cost estimates

Very approximate cost estimates of different types of repairs will be obtained from DOT personnel and local contractors, on a per unit basis. Formulations may include a fixed mobilization fee.

6.4 Effect of repair/remediation/maintenance on risk-consequence rating

The effect of different Repair/Remediation/Maintenance treatments on the rating system can be treated by assuming ratings based on what the face might be like after maintenance.

6.4.1 Scaling

Scaling is used to remove loose, unstable, and overhanging materials from the rock face. The effects on the ratings are:

1. Face instability is decreased.
2. Face looseness is decreased.
3. Face irregularity is decreased
4. Rock fall quantity is decreased.
5. Ditch capacity is increased (ERFQ decreased).

6.4.2 Ditch improvements

Ditch improvements include widening the ditch, increasing its depth and back slope, and using shoulder fence or Jersey barrier to increase capacity. The effects on the ratings are:

1. Ditch width is increased.
2. Ditch volume is increased.
3. Ditch shape factor is increased.
4. Ditch effectiveness is increased (because of increased ditch volume).

6.4.3 Draped mesh

Draped mesh is an effective method to protect the highways from falling rocks, by draping a wire mesh over the slope to retard the energy of falling rock. The effects on the ratings are:

1. Ditch shape is effectively increased in non-vertical faces the simpler ditch criteria can be used.

6.4.4 Cutting back (blasting) the slope

Cutting back the slope, typically by blasting will have a particularly large benefit on the rating system, especially when good perimeter blasting technique replaces earlier poor blasting technique. The effects on the ratings are:

1. Face instability
2. Face irregularity is decreased.
3. Face looseness is decreased.
4. Face instability is decreased.
5. Weathering is decreased.
6. Ditch width is increased.
7. Ditch volume is increased.
8. Ditch shape is increased.
9. Ditch capacity is increased.
10. ERFQ is decreased.

7. Conclusions

As a result of this funding, a cost effect risk-consequence rating system (MORFH RS) has been developed for the State of Missouri.

7.1 Risk-Consequence scheme

Unlike schemes used by other States, MORFH RS is effective because it clearly separates the risk and consequence elements. Risk is defined as the relative likelihood of rock fall, while consequence is the likelihood of negative consequences on the highway, vehicles and people, if there is a rock fall. Lumping these two together makes no sense. High risk slopes are unimportant if there is no consequence to failure. High consequence slopes are unimportant if there is no risk of failure. In addition, some parameters like block size and slope angle may improve the risk index while degrading the consequence index and vice versa.

MORFH RS is designed to do relative rating, to give clear and objective priorities to rock cut maintenance, so that the highways can be safer and legal due diligence is achieved. It uses simple to measure/estimate parameters that can be universally applied to Missouri rock cuts.

7.2 Mobile video logging and measurements on images

MORFH RS is efficient because it utilizes fully mobile video imaging technology to do video logging of the highway, and identify and screen rock cuts with potential problems for potential study. In addition many of the required parameters can be measured on the digital images acquired form the video logs.

7.3 Error and sensitivity tests.

Sensitivity testing was conducted on the system by considering both the measured parameters and the rated ones.

For the measured properties, the errors in measurement were quantified using RockSee and manual measurements on the field. These errors were then introduced into MORFH RS, as a worst case scenario. It was concluded that these errors were typically negligible.

For the raters, the variability in rating on the MORFH RS final values was considered. It was determined that with few exceptions, the errors were low. There were a few high errors in this study, indicating perhaps that more training of the raters needs to be done.

8. Recommendations

The recommendations that follow from this research are more fully addressed in an upcoming proposal from the authors to MODOT. This concerns implementation of MORFH RS under the following three criteria:

1. Developing a GIS database management system that is compatible with Missouri DOT systems.
2. Populate the database with at least 100 detailed evaluations per month, starting with interstates routes, state highways, and other roads in that order.
3. Facilitate the technology transfer that will empower MODOT to maintain, and upgrade the GIS database, including a copy of the RockSee program, detailed manuals, and training sessions.
4. Developing a Rock fall hazard map for rock cuts along the Missouri State Highways. Figure 97 shows the startup of this rock fall hazard map.

In the alternative, MODOT should be prepared to undertake the population of the GIS database.

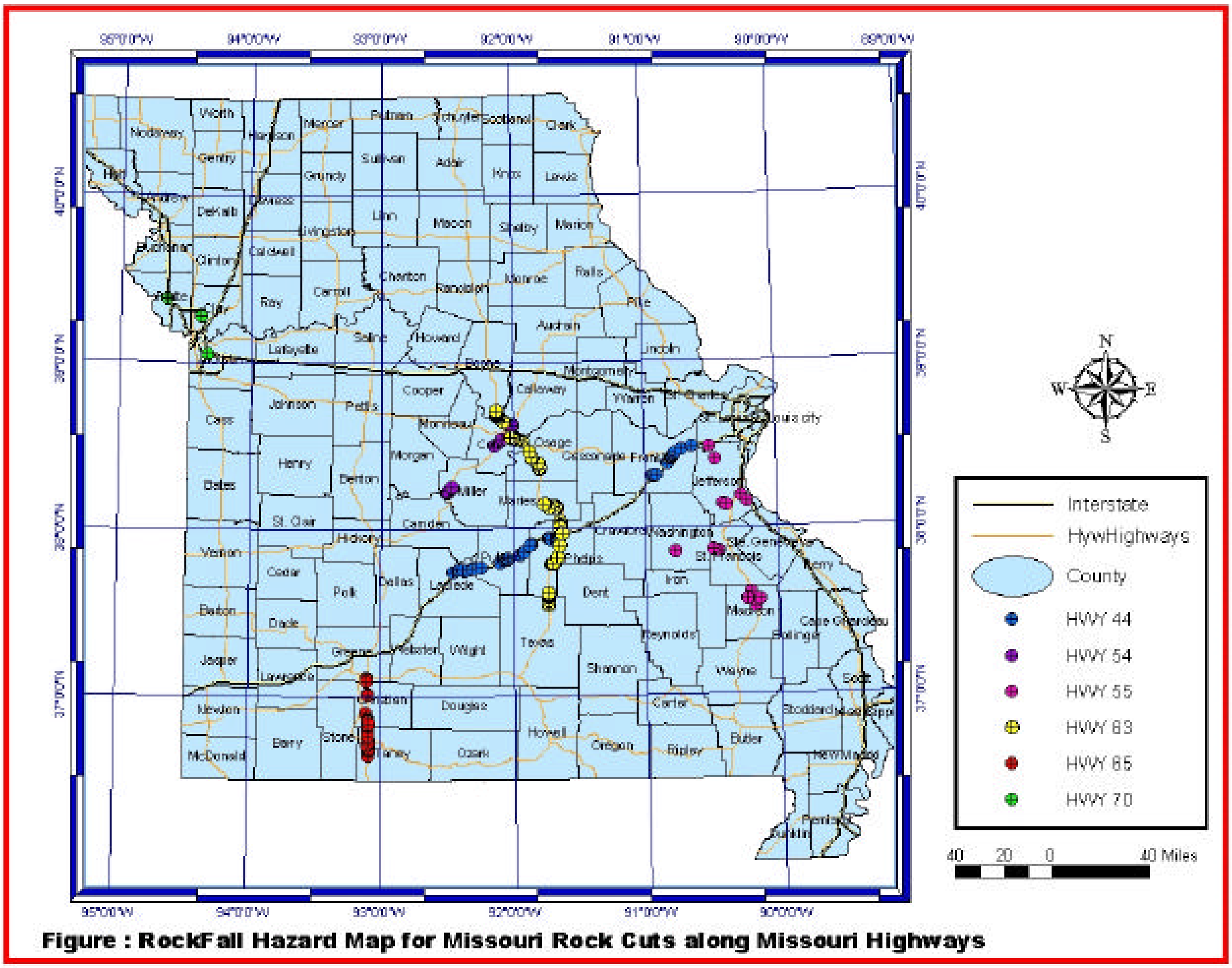


Figure 97: Rock fall Hazard Map for Missouri Rock Cuts.

9. Implementation Plan

See section 8 (above).

10. References

Ali, K. M., and Hasan, K., 2002. Rock mass characterization to indicate slope instability at Bandarban, Bangladesh: A rock engineering systems approach. Environmental & Engineering GeoScience, v. VIII, no. 2, 00. 105-119.

Azzoni, A., La Barbera, G. and Zaninetti, A. 1995. Analysis and prediction of rock falls using a mathematical model. International Journal of Rock Mechanics and Mining Science and Geomechanics Abstracts. Vol. 32., No. 7. p. 709-724.

Badger, T.C. and Lowell, S. 1992. Rockfall Control Washington State. In Rockfall Prediction and Control and Landslide Case Histories, Transportation Research Record, National Research Council, Washington, No 1342, pp 14-19.

Beck, B. F. and S. Sayed, 1991. The sinkhole hazard in Pinellas County: A geologic summary for planning purposes. Winter park, Fl, Florida Sinkhole Research Institute.

Bieniawski Z. T. Engineering Rock Mass Classifications p. 251. Wiley, New York (1989).

Bozzolo, D., Pamini, R. and Hutter, K. 1988. Rock fall analysis - a mathematical model and its test with field data. Proc. 5th International Symposium on Landslides, Lusanne. July 1988, Vol. 1, pp. 555-560.

Brawner, C. O. 1994. Rock fall Hazard Mitigation Methods. Participant Workbook: FHWA Report – FHWA-SA-93-085.

Brawner, C. O., and D. C., Wyllie. 1975. Rock Slope Stability on Railway Projects. In Proc., American Railway Engineering Association Regional Meeting, Vancouver, B. C., American Railway Engineering Association, Washington, D.C., 8 pp.

Bukovansky, M., and Piercy, N. H., high road cuts in a rock mass with horizontal bedding; sixteenth Symposium on Rock Mechanics September 22-24, 1975. pp 71-76.

Descoeudes, F., and T. Zimmerman 1987. Three dimensional calculation of rock falls. In Proc., Sixth International Congress on Rock Mechanics, Montreal, Canada, International Society for Rock Mechanics, Lisbon, Portugal, pp. 337- 342.

Edwin, B. E., Highway Research Board special report 29 Landslides and Engineering Practice (by the committee on landslide investigations 1958 Washington, D. C.)

Evert Hoek's Practical Rock Engineering 2000

Franklin, J. A., and Senior, S. A., 1987a. Outline of RHRON, the Ontario rock fall hazard rating system: Proceedings International Symposium on Engineering Geology and The Environment, Athens, Greece, pp. 647-656.

Franklin, J. A., and Senior, S. A., 1987b. Rock fall Hazards – Strategies for detection, assessment, and remediation: Proceedings International Symposium on Engineering Geology and The Environment, Athens, Greece, pp. 657-663.

Geological Society Engineering Group Working Party, 1995a, Strength Scale for Soils and Rocks: Information Card prepared by Soil Mechanics, U. K.

Geological Society Engineering Group Working Party, 1995a, The description and classification of weathered for engineering purposes: Quarterly Journal of Engineering Geology, Vol. 28, pp. 207 – 242.

Hoek, E. 1986. Rock fall: a computer program for predicting rock fall trajectories. Unpublished internal notes, Golder Associates, Vancouver.

Hoek, E., and Bray, J., 1981. Rock Slope Engineering: The Institution of Mining and Metallurgy, 358 pp.

Hungr, O. and Evans, S.G. 1989. Engineering aspects of rock fall hazard in Canada. Geological Survey of Canada, Open File 2061, 102 pages. Lowell, S. M. 1990. The K M Mountain landslide near Skamokawa, Washington. Washington Geologic Newsletter, Vol. 18, No. 4, pp. 3-7.

Hungr, O. and Evans, S.G. 1989. Engineering aspects of rockfall hazard in Canada. Geological Survey of Canada, Open File 2061, 102 pages.

ISRM suggested methods quantitative description of discontinuities in rock masses. Int J. Rock Mech. Min. Sci. and Geomech. Abstr. 15, 319 – 368 (1978).

Maerz, N. H., 2002. Mobile vision system for screening and evaluation of highway rock cut stability problems. AEG 45th Annual Meeting, Reno, NV, Sept. 23-29, 2002.

Maerz, N. H., and McKenna, S, 1999. Mobile highway inventory and measurement system. Transportation Research Record No. 1690, pp. 135-142.

Maerz, N. H., and McKenna, S., 1999. Mobile highway inventory and measurement system. Transportation Research Record No. 1690, pp. 135-142.

Maerz, N. H., Youssef, A. M., and Qinfang, 2003. Digital imaging for screening and making measurements of features on highway rock cuts. To be presented, Transportation Research Board, 82nd Annual Meeting, Washington, D.C., Jan. 12-16, 2003.

Mathis, J. Bench Face Design in Rock (short course 2003).

McCauley, M. L., B. W. Works, and S. A. Naramore. 985. Rockfall Mitigation. Report FHWA/CA/TL-85/12. FHWA, U. S. Department of Transportation, 147 pp.

NHI (National Highway Institute), 1993. Rock fall Hazard Rating System. Publication No. FHWA SA-93-057.

NHI (National Highway Institute), 1994. Rock fall Hazard Mitigation. Publication No. FHWA SA-93-085.

NYDOT (New York Department of Transportation), 1996. Rock Slope Rating Procedure (GEM-15), June, 1966.

Peckover, F. L. 1975. Treatment of Rockfalls on Railway lines. Bulletin 653. American Railway Engineering Association, Washington, D.C., pp. 471-503.

Pfeiffer, T. J., and T. D. Bowen 1989. Computer Simulation of Rockfall. Bulletin of The Association of Engineering Geology, Vol. 26, No. 1, pp. 135 – 146.

Pfeiffer T. J., J. D. Higgins, and A. K. Turner. 1990. Computer aided Rockfall Hazard Analysis. In Proc., Sixth International Congress of the International Association of Engineering Geology, Amsterdam, A.A. Balkema, Rotterdam, Netherlands, pp. 93 – 103.

Pierson, L. A., and Van Vickle, R., 1993, Rock fall Hazard Rating System – Participants' Manual: FHWA Report – FHWA-SA-93-057, 102 pp.

Pierson, L. A., S. A. Davis, and R. Van Vickle. 1990. The Rockfall Hazard Rating System: Implementation Manual. Technical Report FHWA- OR- EG-90-01. FHWA, U. S. Department of Transportation.

Piteau, D. R., 1979a, Engineering geology considerations and basic approach to rock slope stability analysis for highways. Part A., Rock Slope Engineering Reference Manual: FHWA Report – FHWA-TS-79-208, 78 pp.

Piteau, D. R., 1979d, Slope stability analysis methods. Part D, Rock Slope Engineering Reference Manual: FHWA Report – FHWA-TS-79-208.

Piteau, D. R., 1979e, Rock slope stabilization, protection and warning-instrumentation measures and related construction considerations. Part E, Rock Slope Engineering Reference Manual: FHWA Report – FHWA-TS-79-208.

Piteau, D. R. 1972. Engineering Geology Considerations and approach in Assessing the stability of rock slopes. Bulletin of the Association of Engineering Geologists, Vol. 9, No. 3, pp. 301 – 320.

Piteau, D. R., and Associates Ltd, 1979a. Rock Slope Engineering Reference Manual. Part D: Slope Stability Analyses Methods. Publication No. FHWA TS-79-208.

Piteau, D. R., and Associates Ltd, 1979b. Rock Slope Engineering Reference Manual. Part E: Rock Slope Stabilization, Protection and Warning-Instrumentation Measures and Related Construction Considerations. Publication No. F.

Piteau, D. R. 1980. Slope Stability Analysis for rockfall problems: The computer rockfall model for simulating rockfall distribution. In rock slope engineering, part D, Reference manual FHWA-TS-79 – 208, FHWA, U. S. Department of Transportation, pp. 62 – 68.

Ritchie, A.M. (1963); Evaluation of rock fall and its control; Highway Research Record, #17, pp 13-28

Saltelli, A., Chan, K., & Scott, E. M. 2000. Sensitivity Analysis. John Wiley & Sons.

Singh, B. and Goel, R. K., 1999. Rock Mass Classification. A Practical Approach in Civil Engineering: Elsevier, 267 pp.

Spang, R. M. 1987. Protection against rock fall Stepchild in the Design of rock slopes. In Proc., Sixth International Congress On Rock Mechanics, Montreal, Canada, International Society for Rock Mechanics, Lisbon, Portugal, pp. 551- 557.

Spang, R.M. and Rautenstrauch, R.W. 1988. Empirical and mathematical approaches to rock fall prediction and their practical applications. Proc. 5th International Symposium on Landslides, Lusanne. Vol. 2. 1237-1243.

Turner, A. K., and Schuster, R. L., 1996. Landslides investigation and mitigation. Special report 247. National Academy Press, Washington, D. C.

Unklesbay A.G. and Vineyard J.D. (1992) Missouri Geology, Three Billion Years of Volcanoes, Seas, Sediments and Erosion, Univ. of Missouri Press, Columbia, Missouri, 189 pp.

Wu, S- S.1984. Rockfall evaluation by computer simulation. In transportation research record 1031, TRB, National Research Council, Washington, D. C., pp 1-5.

Wyllie, D. C. 1987. Rock slope inventory system. In Proc., Federal Highway Administration Rockfall Mitigation Seminar, FHWA Region 10, Portland, Oreg., 25 pp.

APPENDIX A: User Manual for RockSee and MORFH RS

A.1 Introduction to RockSee version 1 and 2

RockSee 1 and 2 (the geotechnical program for screening, measuring features, and rating rock cuts along Highways) is a revolutionary image analysis system. From its inception, RockSee was designed to address the numerous and specific needs of those who regularly use image analysis of the rock cut data. RockSee provides comprehensive data visualization, measurements, and rating analysis for AVI images of any size all from within an innovative and user-friendly environment.

A.2 Advantages of RockSee

One of RockSee's strengths lies in its unique approach to image screening, measurements, and rating in one step. RockSee's strong visual interface is complemented by its comprehensive library of processing algorithms. RockSee's uses many basic processing functions, which are used to determine the rating value for all parameters.

A.3 RockSee and Visual C++ Language

RockSee is written in Visual C++ Data Language, a powerful structured programming language that offers integrated image processing.

A.4 Starting RockSee

Before starting RockSee, ensure that it is properly installed as described in the installation guide. To start RockSee from a Windows system, Select Start / Programs / RockSee. The main RockSee interface appears when the program has successfully loaded and executed Figure 98. It is also easy to start RockSee program if you have a shortcut on the desktop.

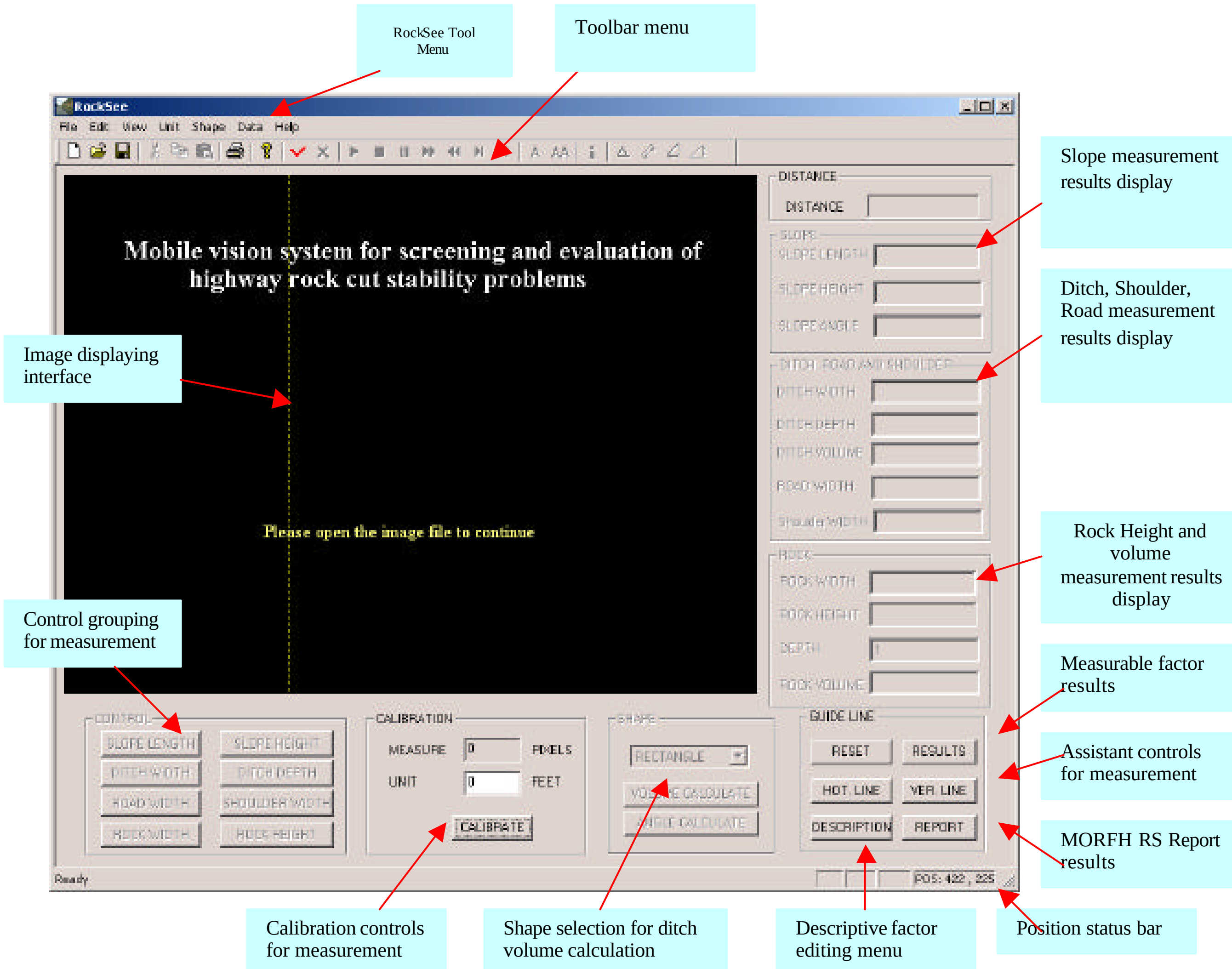


Figure 98: Shows the main RockSee interface

A.5 RockSee Basics

This section describes standard RockSee file opening procedures and options.

A.5.1 Selecting Files in RockSee

Before you apply any of RockSee's functions to a specific data set, you must first select the file containing the data. To ensure consistency, nearly every RockSee image processing function uses an AVI standard input file selection dialog. Figure 99 shows the tool bar functions in RockSee program.

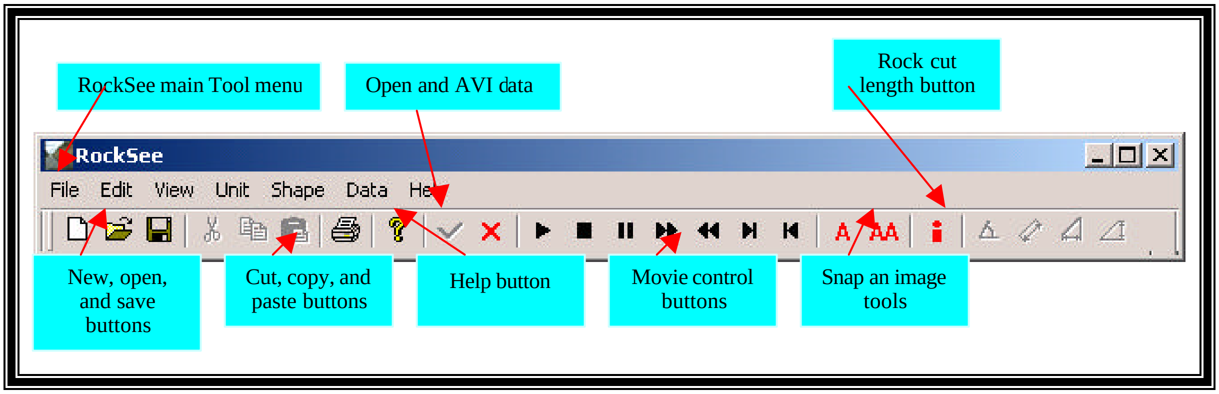


Figure 99: RockSee Menu and Toolbar functions

A.5.2 File Tool Menu

Use the file Tool menu to access a variety of RockSee functions. The functions are generally useful as get a new interface, open file, save file, save file as, print, print view, print setup, and exit the program.

A.5.3 View Tool Menu

Use the View Tool menu to access a variety of RockSee functions as toolbar and status bar. The toolbar will used to show the toolbar in the RockSee interface, the status bar will show the position of the mouse any where in the image.

A.5.4 Unit Tool Menu

Use the Unit Tool menu to access a unite types that we need to use during the measurements. We have to unites we can use here meters and feet.

A.5.5 Shape Tool Menu

Use the Shape Tool menu to access the type of rating system we need to use. There are two type of rating systems applied for the MORFH RS, which are normal and the other one if there is a bad bench and or slope face.

A.5.6 Data Tool Menu

Use the Data Tool menu to edit the descriptive data table and GPS data for the rock cut site.

A.5.7 How to Open an AVI Movie

A.5.7.1 Opening an AVI movie from file tool

1- Click the file tool then open button.
2- Click the Look in dropdown arrow and navigate to the folder that contains the AVI data.
3- Click the Movie you want to open.
4- Click Open.

A.5.7.2 Opening an AVI movie from Toolbar

1- Click the Open button  or on the Standard toolbar.
2- Click the Look in dropdown arrow and navigate to the folder that contains the AVI Movie.
3- Click the AVI Movie you want to open.
4- Click Open.

A.5.7.3 Opening a recently opened AVI movie

1- Click the File menu.
2- Click an AVI Movie from the list of recently opened AVI Movies.

Tips
You can only work on one AVI Movie at a time in a RockSee session.
RockSee will close any open AVI Movie before opening another one.

A.5.8 How to Play an AVI Movie

1- Click PLAY button to play the video,
2- Click PAUSE button to stop at the current position. When PALY button is clicked, the clip will be played from the stopped position.
3- Click STOP button to stop playing and the position moves to the beginning of video.
4- Click STEP << button to move video forward frame by frame, click STEP >> button to move video back frame from frame,
5- Click HOME button to move video to the beginning, and click
6- END button to move video to the end.
7- Fast move the video to the desired position using the SLIDER bar Figure 100.

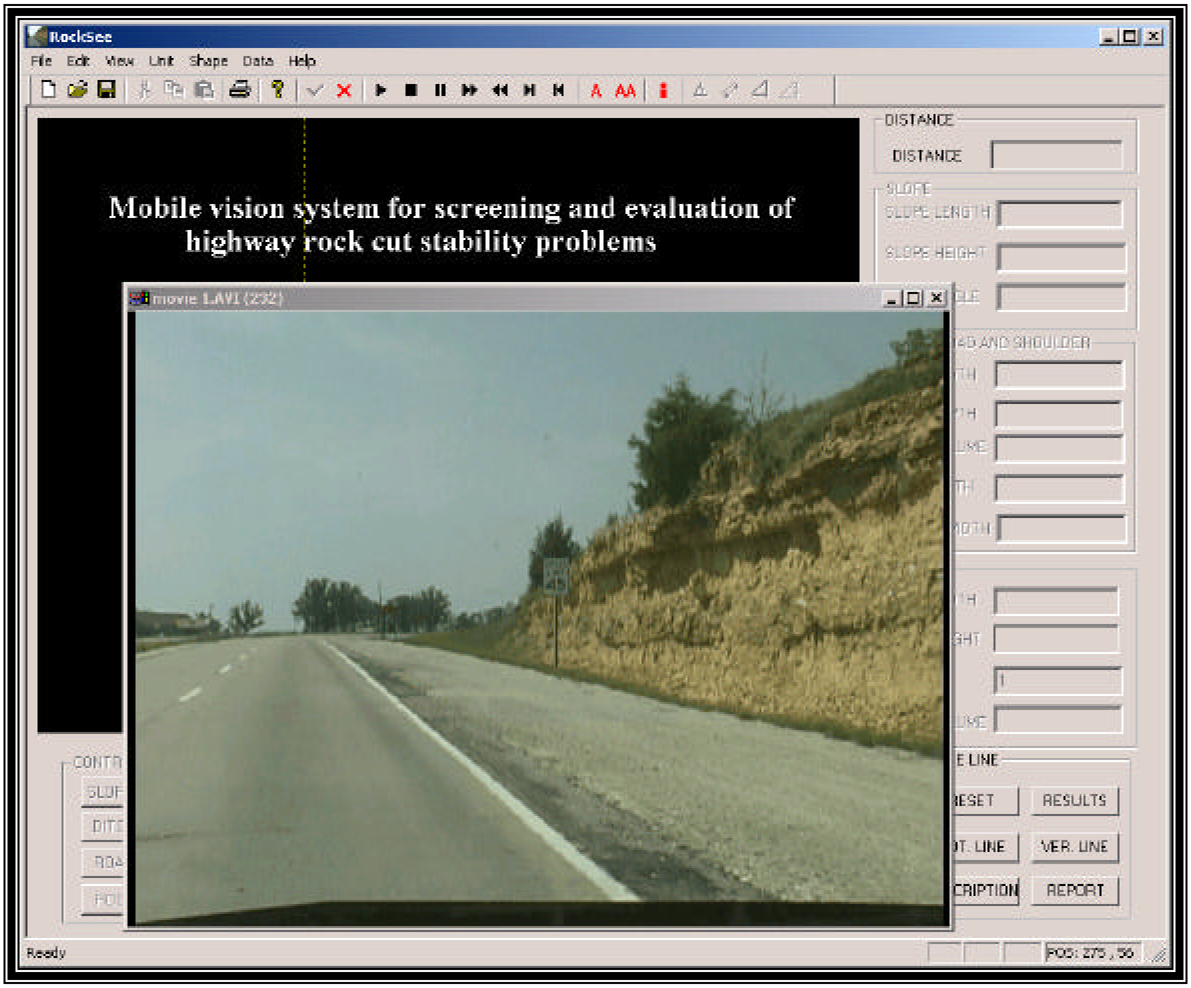


Figure 100: Shows the AVI movie player with the control buttons on the tool bar of RockSee interface.

A.5.9 How to Snap the Frames from AVI Movie

a. Click SNAP A FRAME button (A) to snap a frame at the current position from the video clip.
b. Click SNAP ALL FRAMES button (AA) to snap all frames from the video clip.

A.5.10 Rock Cut Measurement on the Snaped Image

1. Snap the frames from AVI Movie
2. To make a measurements we have to have an image in the RockSee interface
3. Click SNAP A FRAME button (A) to snap a frame at the current position from the video clip.
4. The image will snap and appear on the RockSee interface Figure 101.

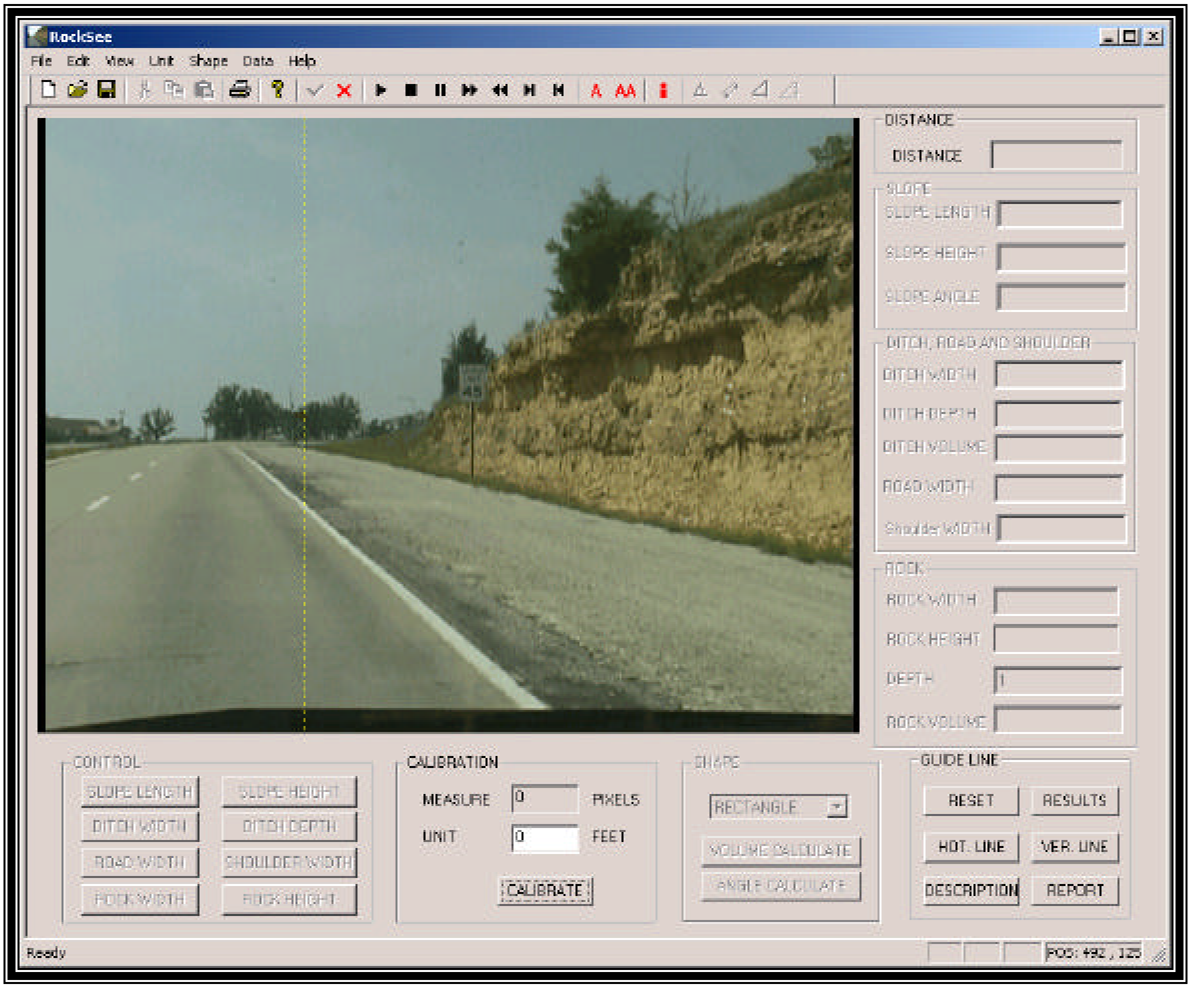


Figure 101: Shows RockSee interface with a snap image.

A.5.11 Using the Measurement Tool

Use Measurement Tool to get a report on the measurable factors in the image between points in a line, to get slope angle for slope, and rock and ditch volumes.

A.5.11.1 Selecting Measurement Units

1. From the unit Tool dialog, use the Units menu to select the unit the measurement is reported in. The choices are meters and feet.
2. Select the desired unit.

A.5.11.2 Calibration Method

1. Measure the distance of projection of the standard object (5 feet rod or other easily identified object as road width if it is constant and does not change much a long the roads) on the image in pixels.
2. Input the real distance of the standard object in foot in the **UNIT** edit box.
3. Click CALIBRATE button to get the calibration in pixels/foot.

A.5.12 Measurement Methods

A.5.12.1 Slope Measurements

1. Click **SLOPE LENGTH** button to begin to measure slope length. Select the start and end point using mouse to get the length of the slope.
2. Click **SLOPE HEIGHT** button to begin to measure slope height. Select the start and end point using mouse to get the height of the slope.
3. Click **ANGLE CALCULATE** button to get the slope angle.

A.5.12.2 Ditch Measurements

1. Click **DITCH WIDTH** button to begin to measure ditch width. Select the start and end point using mouse to get the width.
2. Click **DITCH DEPTH** button to begin to measure ditch depth. Select the start and end point using mouse to get the depth.
3. Select the right shape of ditch from combo control in **SHAPE GROUP**
4. Click **VOLUME CALCULATE** button to get ditch volume.

A.5.12.3 Rock Measurements

1. Click **ROCK LENGTH** button to begin to measure rock length. Select the start and end point using mouse to get the length.
2. Click **ROCK HEIGHT** button to begin to measure rock height. Select the start and end point using mouse to get the height.
3. Input rock depth in the **DEPTH** edit box. The calculated rock volume will be displayed in **ROCK VOLUME** edit box.

A.6 Rating System and RockSee Program

In this section we will discuss how we can use RockSee to determine the rating values for the parameters, get risk and consequence values, and plot these values on a graph to see if we need any type of remediation. The following steps are used to prepare for rating

A.6.1 How to Determine which Rating System Will Be Used

1. Open the shape tool menu
2. Click on the type of rating system you want to use according on the data you have from the site. We use normal rating system if we have a vertical slope and we use bad bench and / or slope rating if we have a negative bench effect or slope face in the site.

A.6.2 Editing the GPS Data

1. Open the data tool menu
2. Click on the GPS data
3. Edit the data that available about the site as site number, highway name, elevation, latitude and longitude for the site, posted speed limit, and car speed Figure 102.
4. Click update to save the data you edit in the RockSee memory

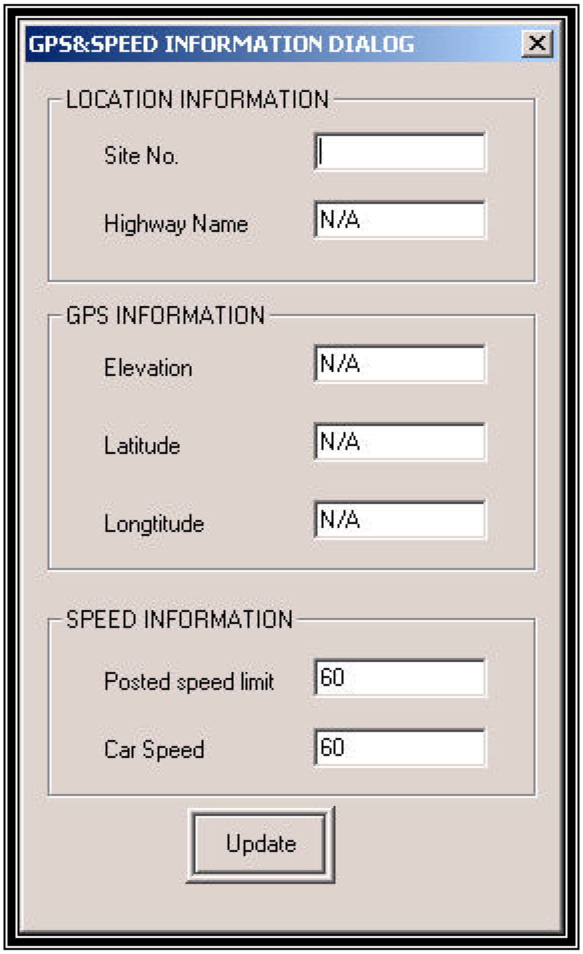


Figure 102: Site, GPS, and speed information dialog

A.6.3 How to Determine the Hazard Zone Length

1. Before playing the AVI Movie click on the icon (i) on the toolbar to activate it to measure the rock cut length in this interface we will see the following data, file name of the movie, date, total frame number, duration of the movie millisecond, and currant position of the measurements.
2. Then click ok
3. Play the Movie till the end of the hazard section
4. If we open the icon (i) again we will see the frame numbers that the RockSee determine for that zone and also the time length for that zone, Figure 103.

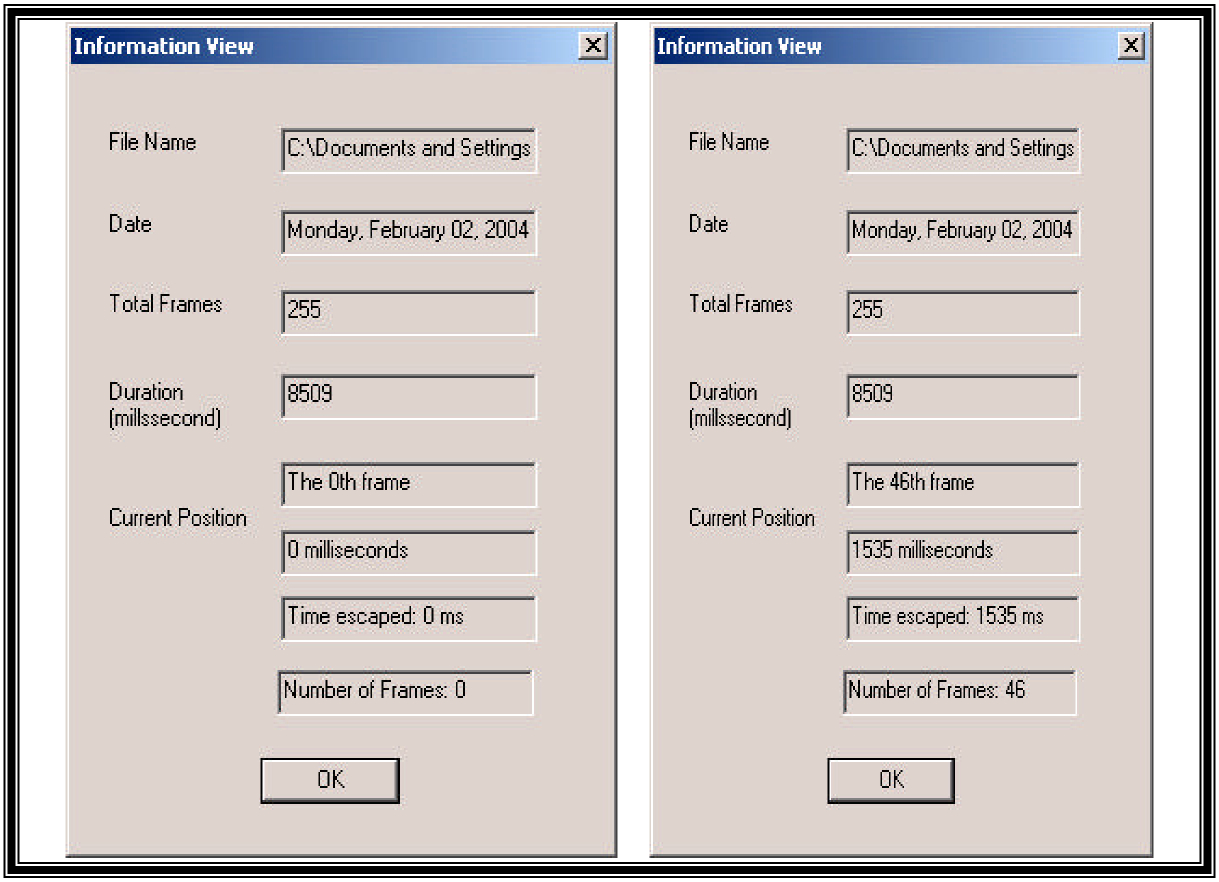


Figure 103: Shows the current position of rock cut length before and after playing the movie

A.6.4 Measurement

1. Click on (A) icon to snap an image to make all different type of measurements.
2. Begin the measurements by setting the calibration.
3. After you finish measurements click on result icon to see the measurement values Figure 104.
4. If there is some parameters can not you measure from the image you can edit it manually
5. Click update to save the measurement values to rating system.

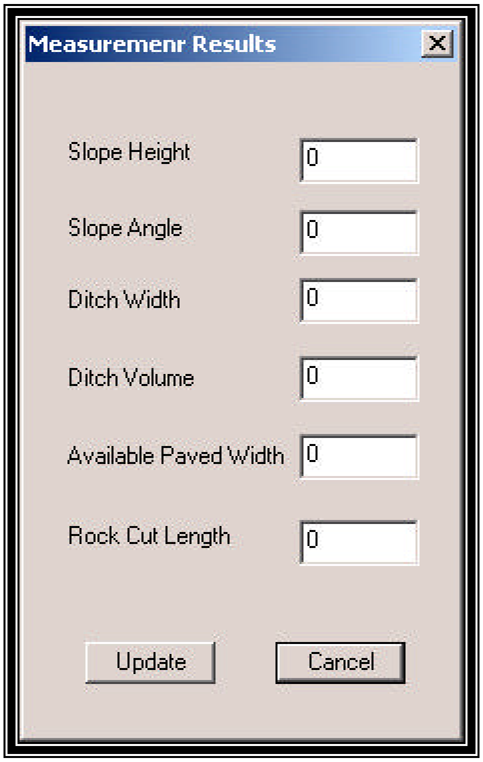


Figure 104: Measurement result table

A.6.5 How to Edit the Descriptive Data

1. Open data tool menu and click descriptive data or click on the descriptive icon in the RockSee program.
2. Descriptive parameter table will appear Figure 105.
3. Edit the value of class number for each parameter that we have from the field and from MODOT records.
4. If you want to see the description for any parameter you can click the description icon in front of each parameter
5. Click update to load the data to the MORFH RS.
6. Then click cancel to finish this part.

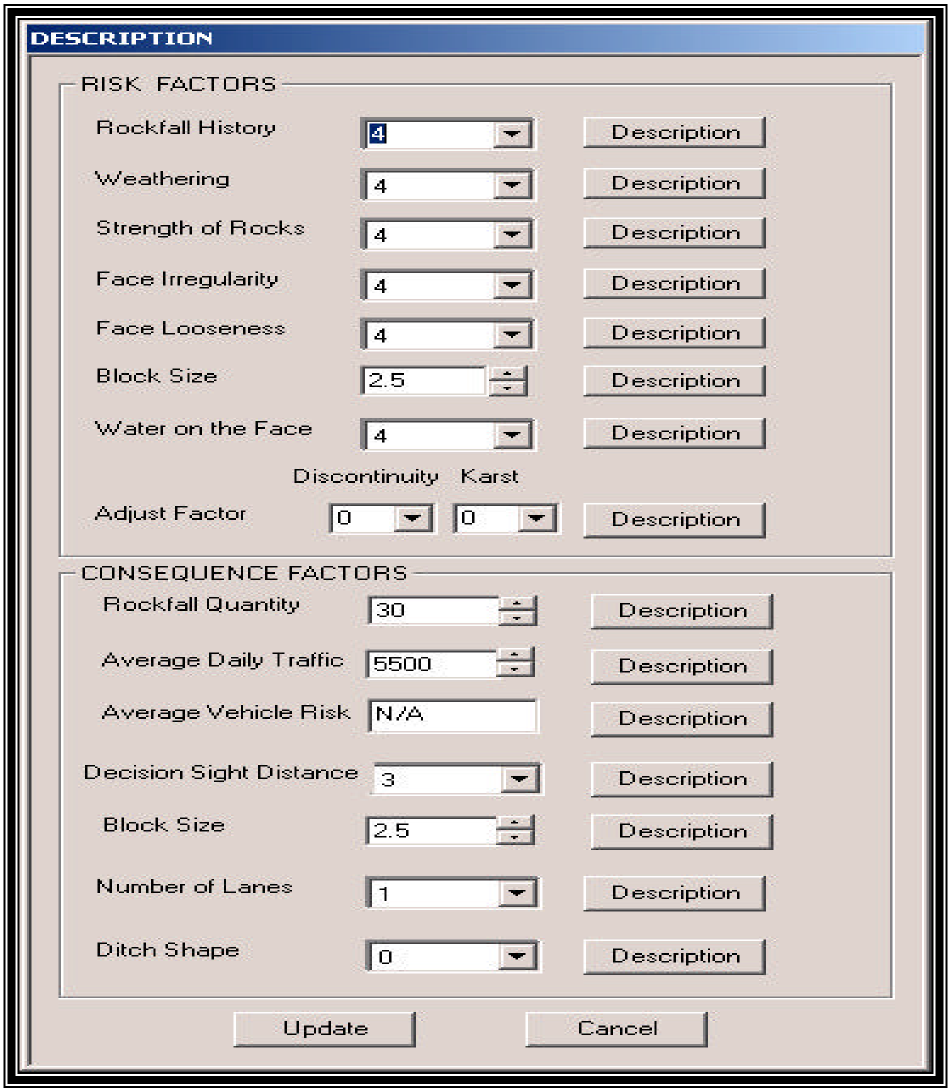


Figure 105: Description data table

A.6.6 MORFH RS Report

1. Click on the report icon in the RockSee Program
2. New window will pop up which consists of, the image that we did the measurements on it, the site and GPS data, measurable and descriptive values, rating values for all parameters, plotting graph for risk consequence value Figure 106.
3. Click copy button to copy the image.
4. Click load button to load the report file in your computer.
5. Click save button to save the report in RockSee extension.
6. Click print button to print the report.
7. Click copy grid button to copy the data values
8. When you finish click x icon to exit the report

Figure 106: Analyses report for rock cut site.

APPENDIX B: Data, Maps, etc.

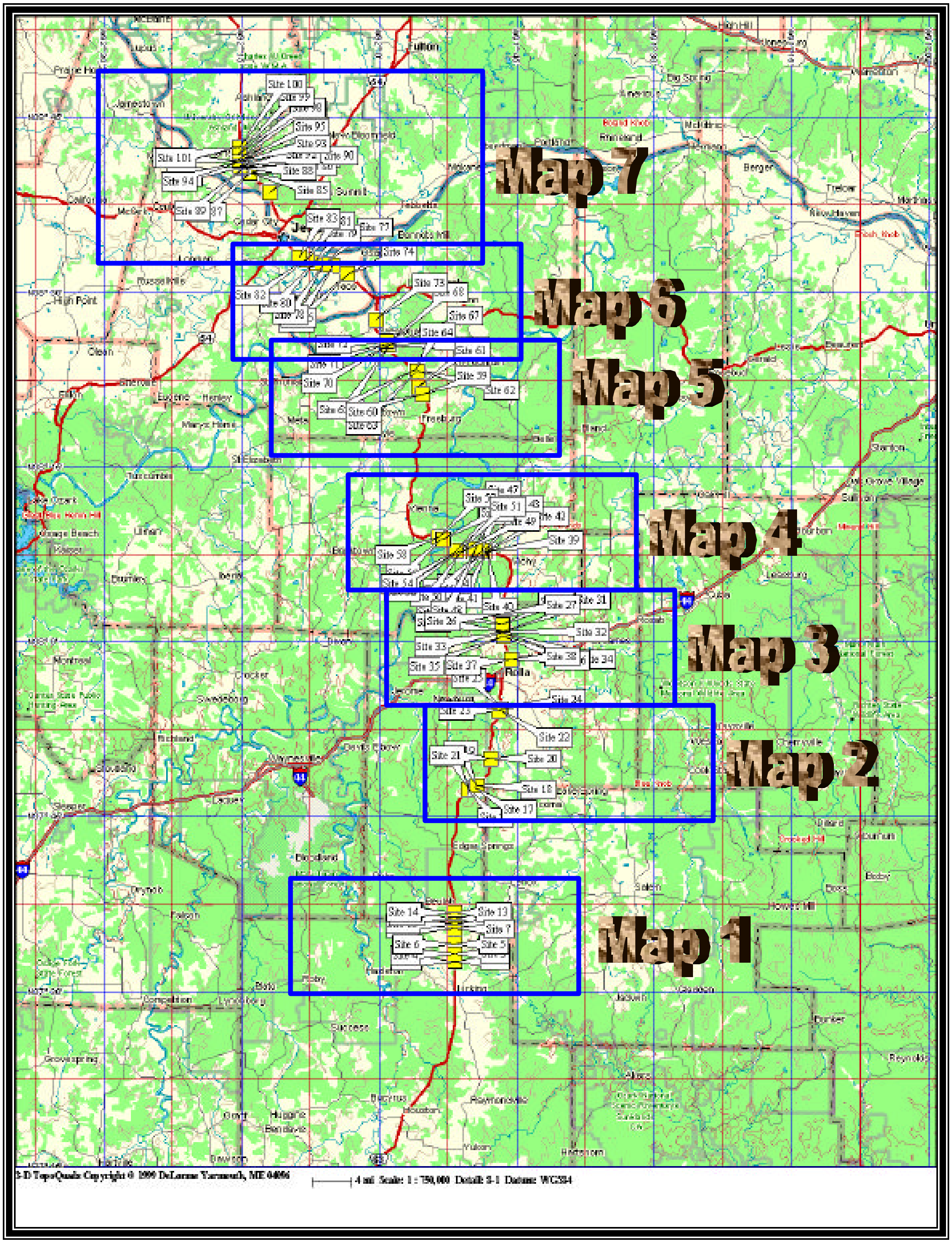


Figure 107: Map showing Highway 63 sites.

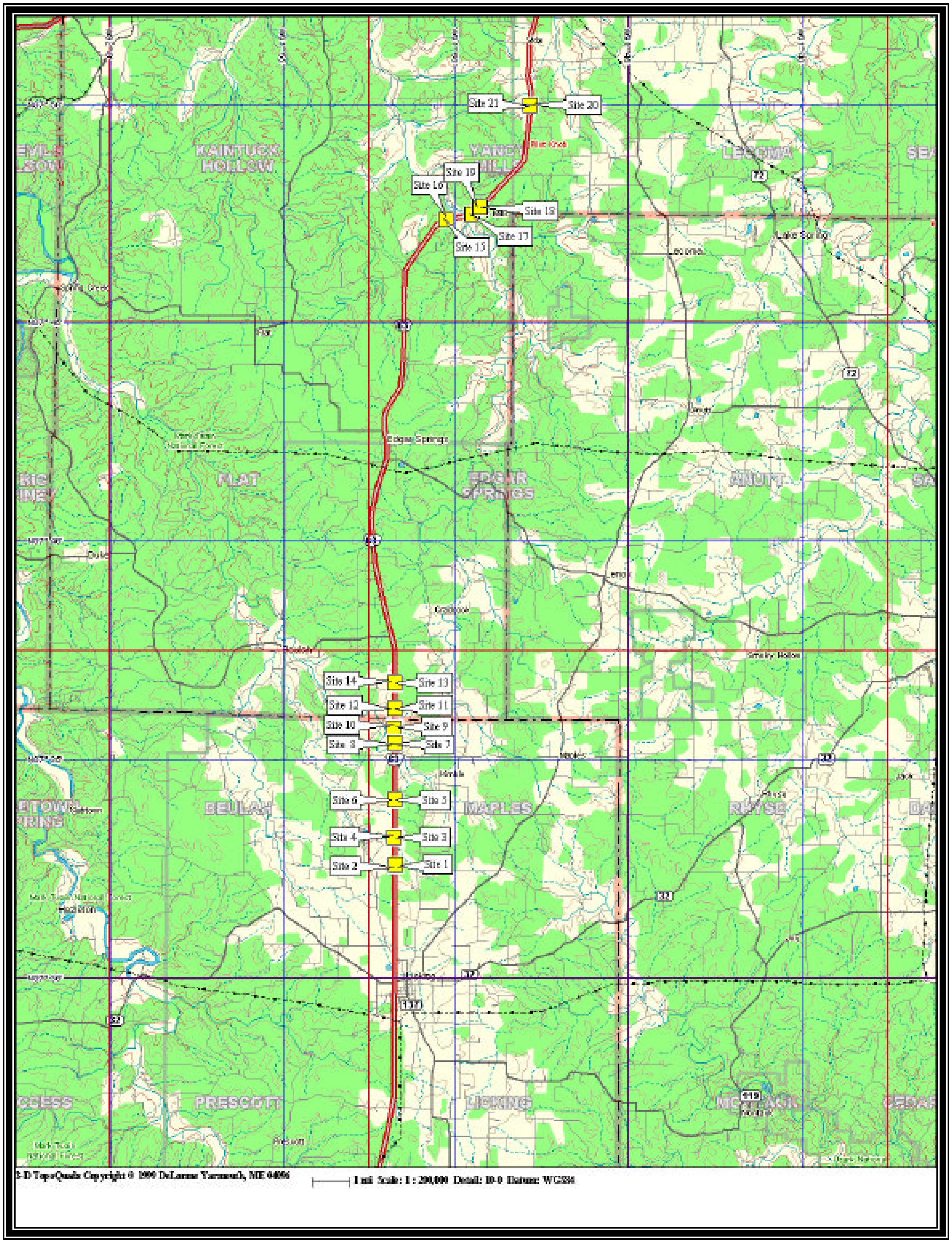


Figure 107a: Map 1 sites (1 - 19) for the rock cuts along Highway 63.

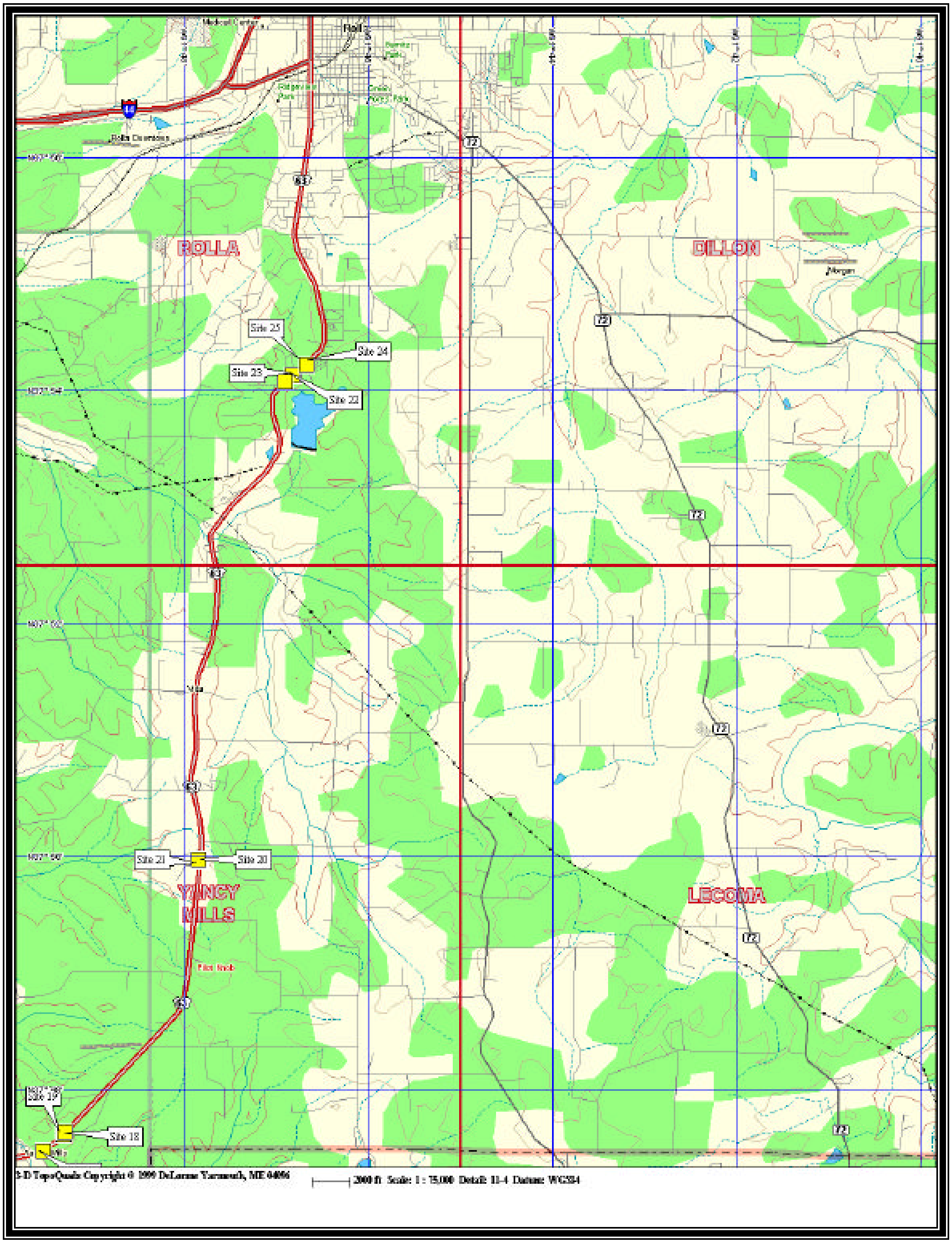


Figure 107b: Map 2 sites (20 - 25) for the rock cuts along Highway 63.

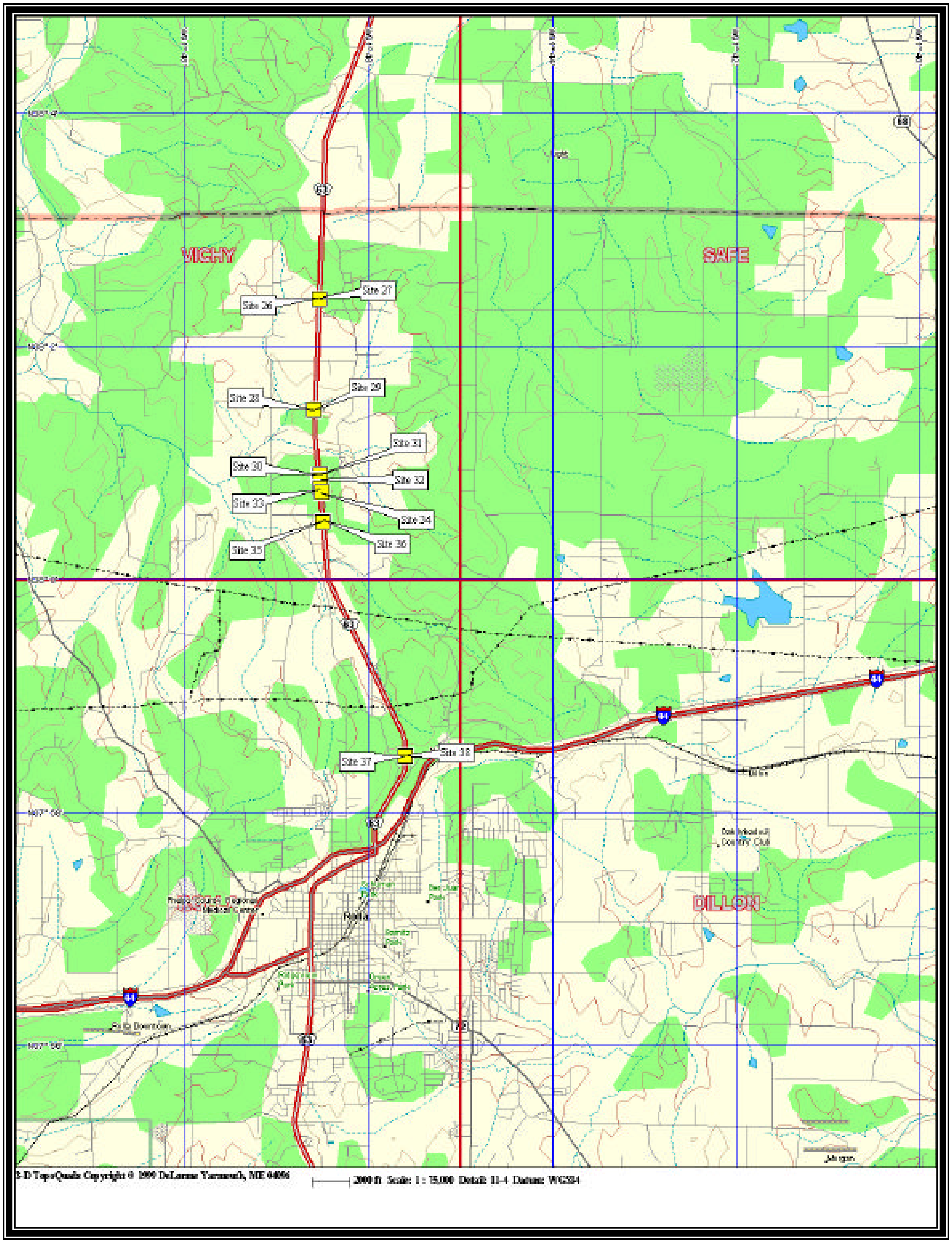


Figure 107c: Map 3 sites (26 - 38) for the rock cuts along Highway 63.

Figure 107d: Map 4 sites (39 - 58) for the rock cuts along Highway 63.

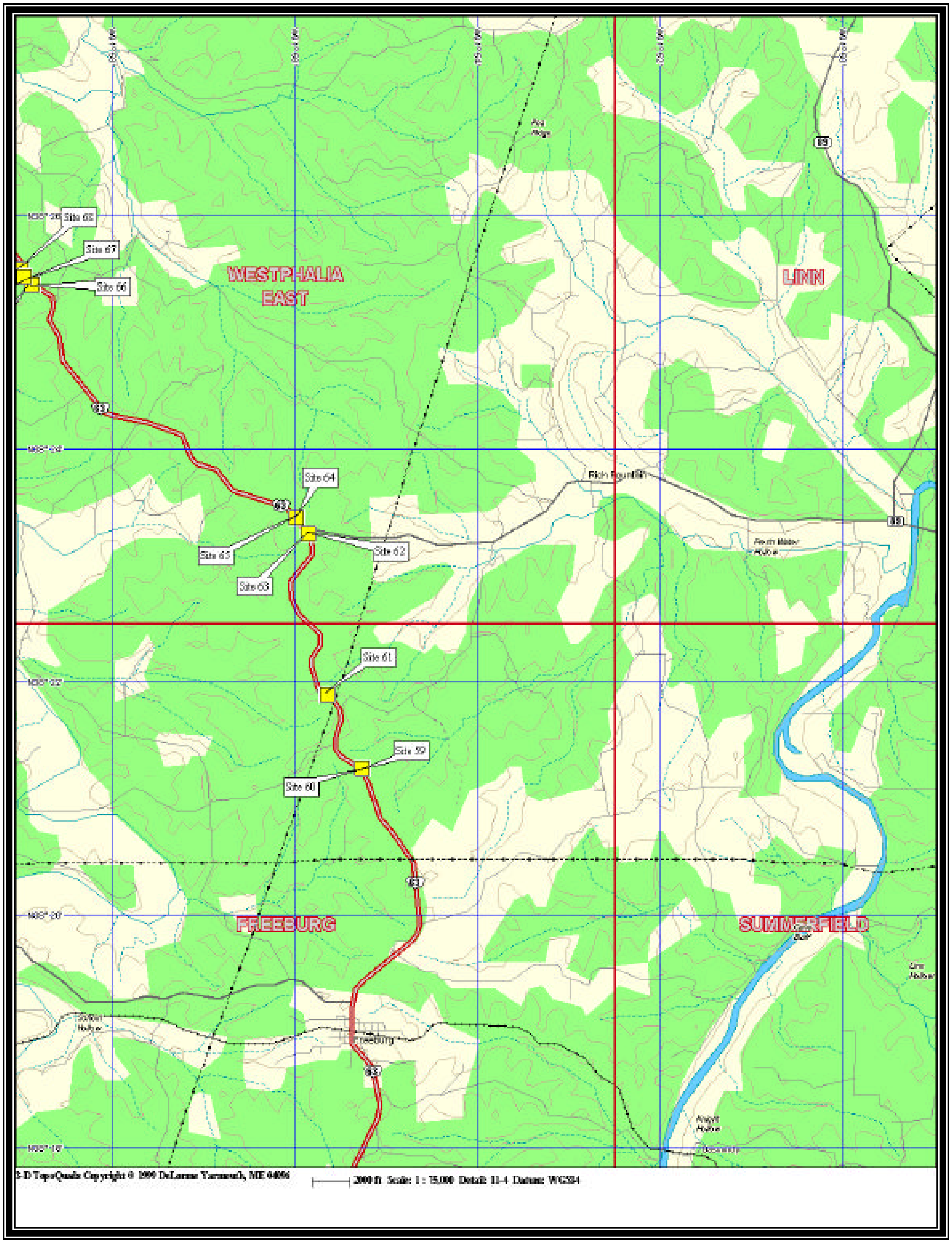


Figure 107e: Map 5 sites (59 - 65) for the rock cuts along Highway 63.

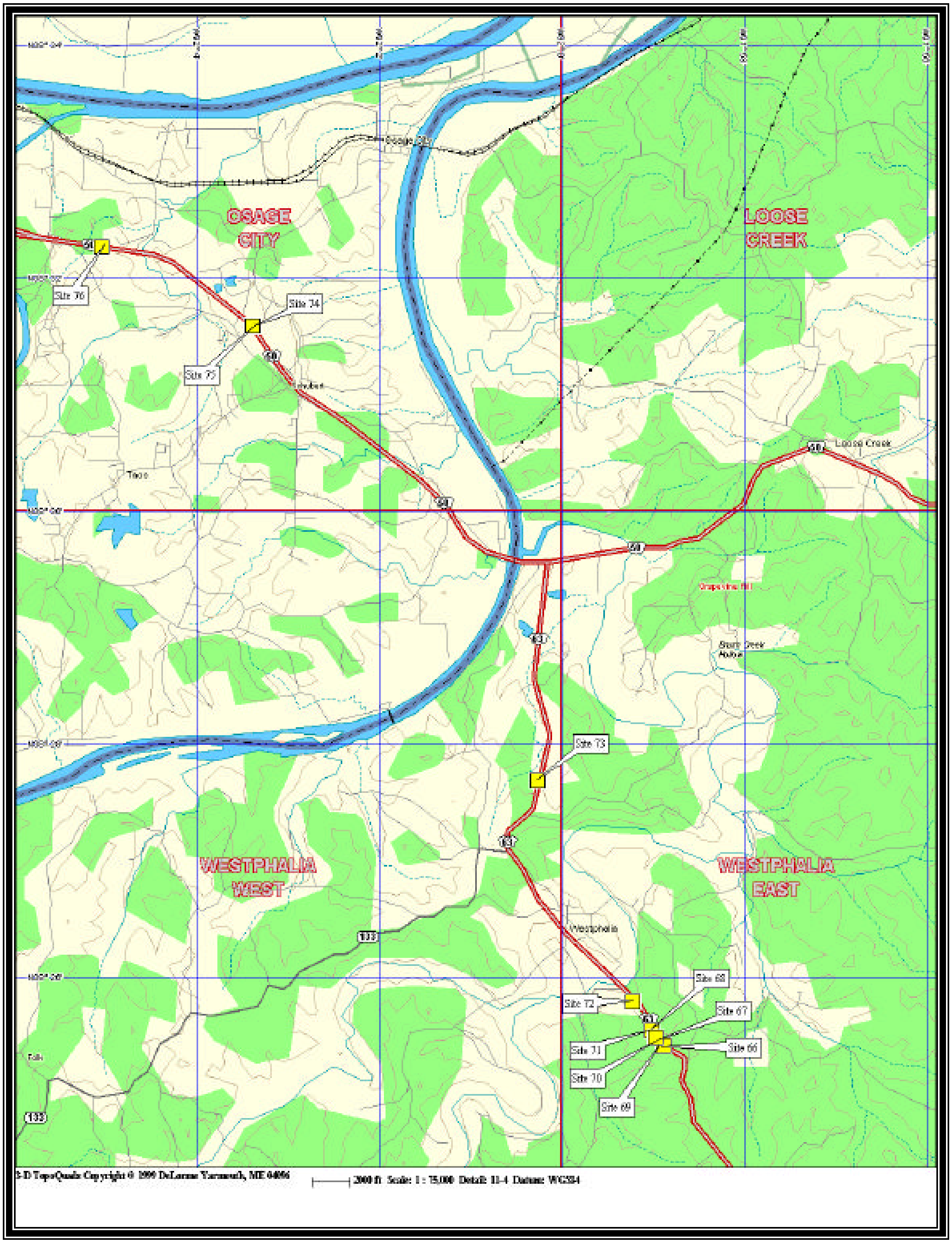


Figure 107f: Map 6 sites (66 - 76) for the rock cuts along Highway 63.

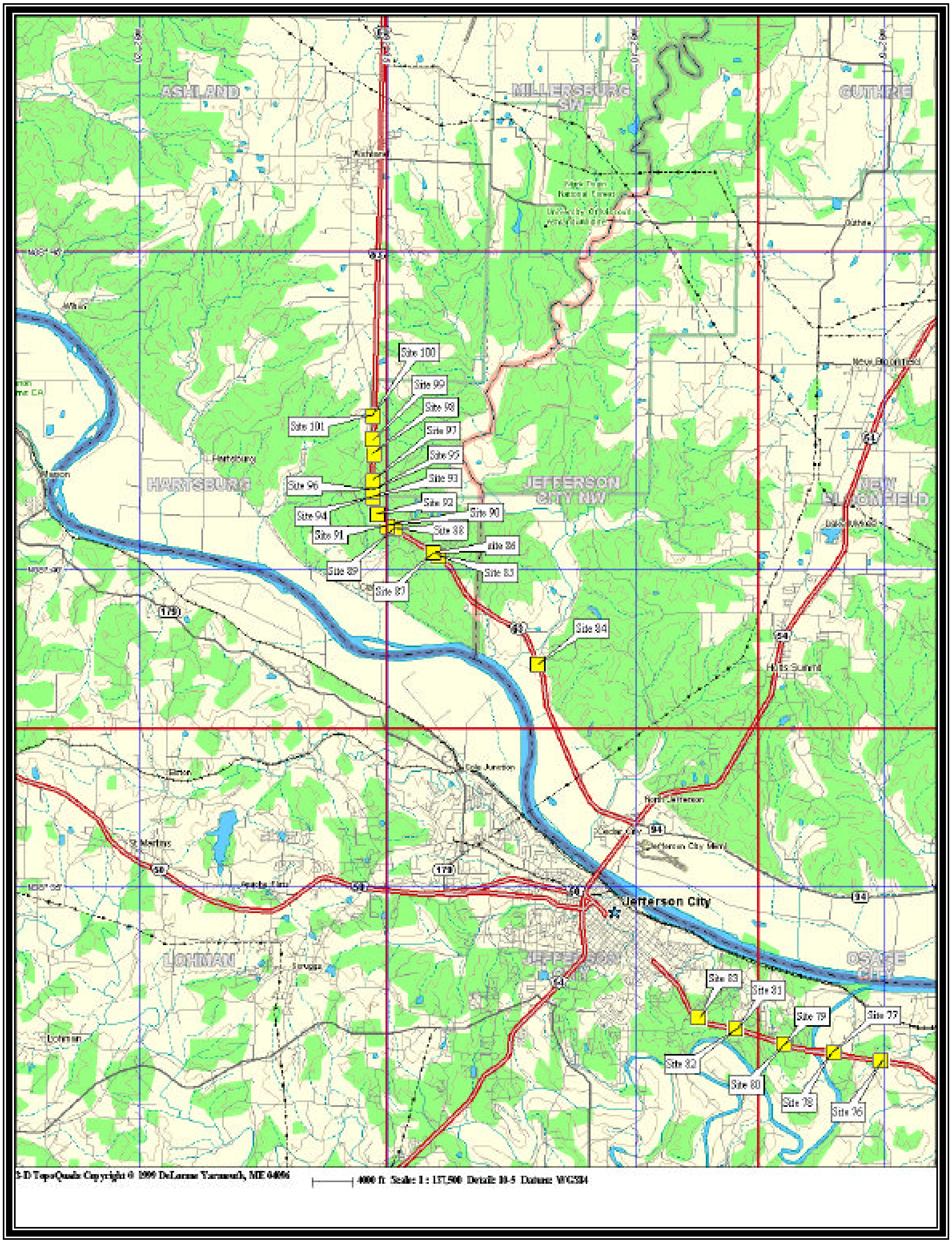


Figure 107g: Map 7 sites (77 - 101) for the rock cuts along Highway 63.

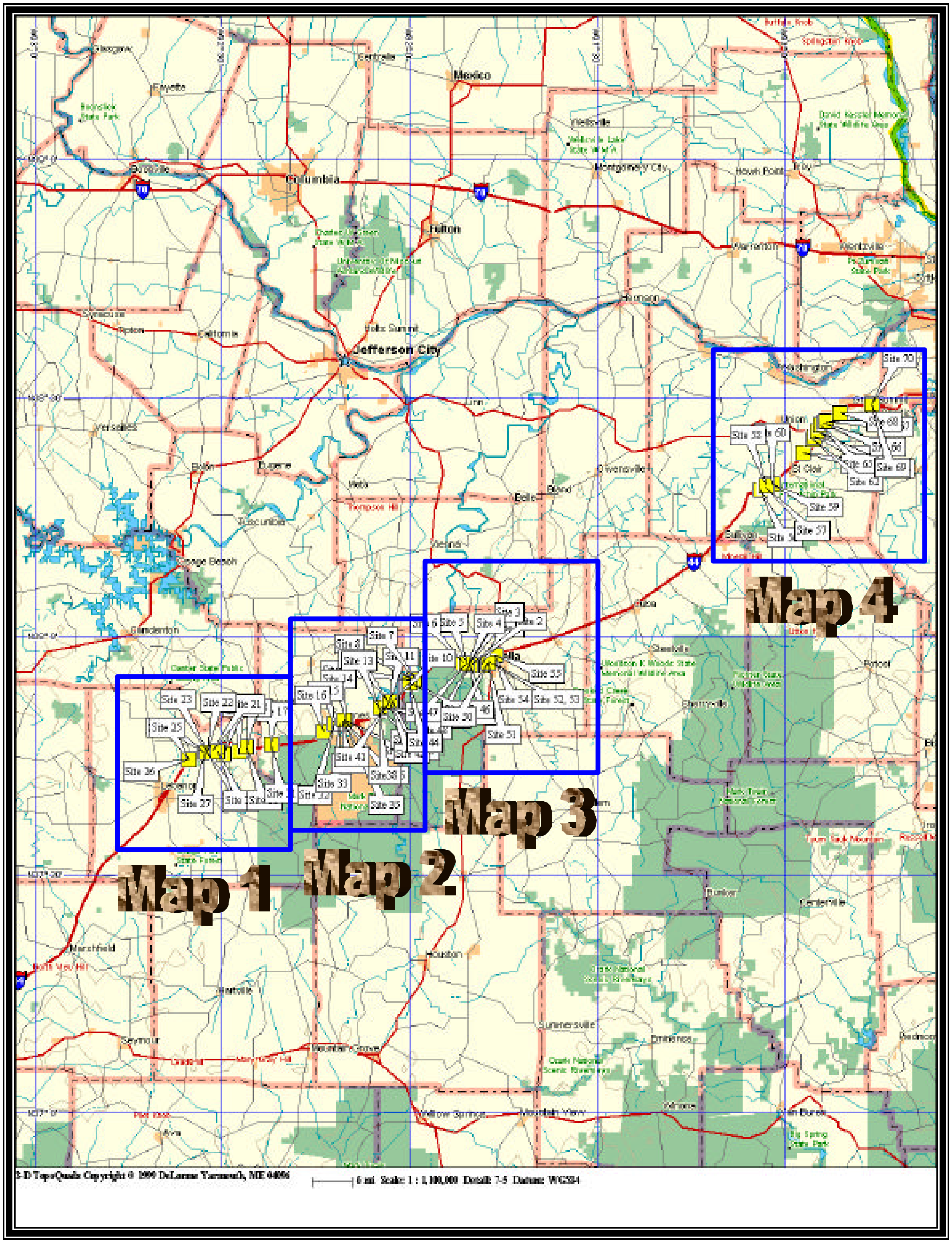


Figure 108: Map showing all sites along Highway 44.

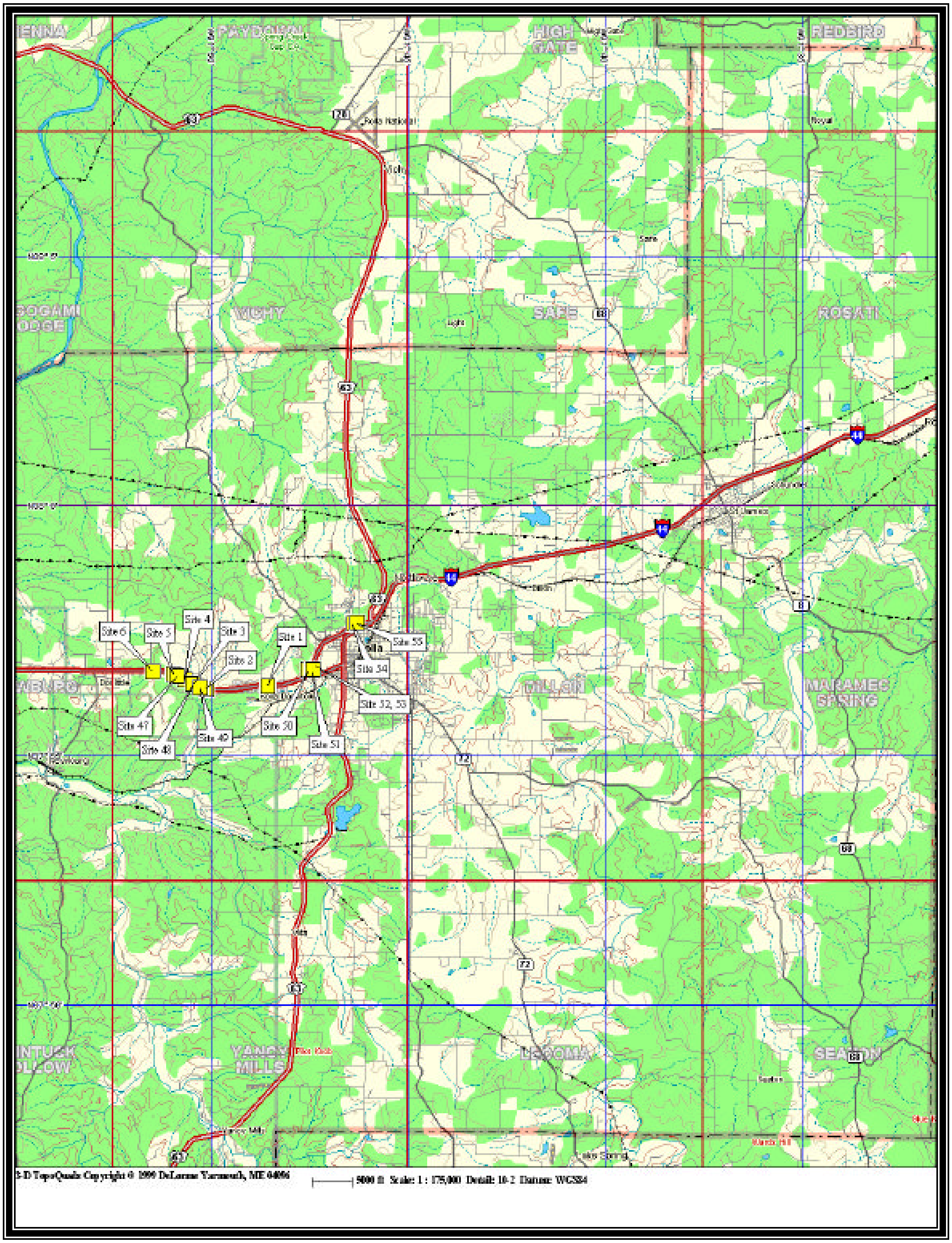


Figure 108a: Map 1 shows sites (1-6) and (47-55) for the rock cuts along Highway I-44.

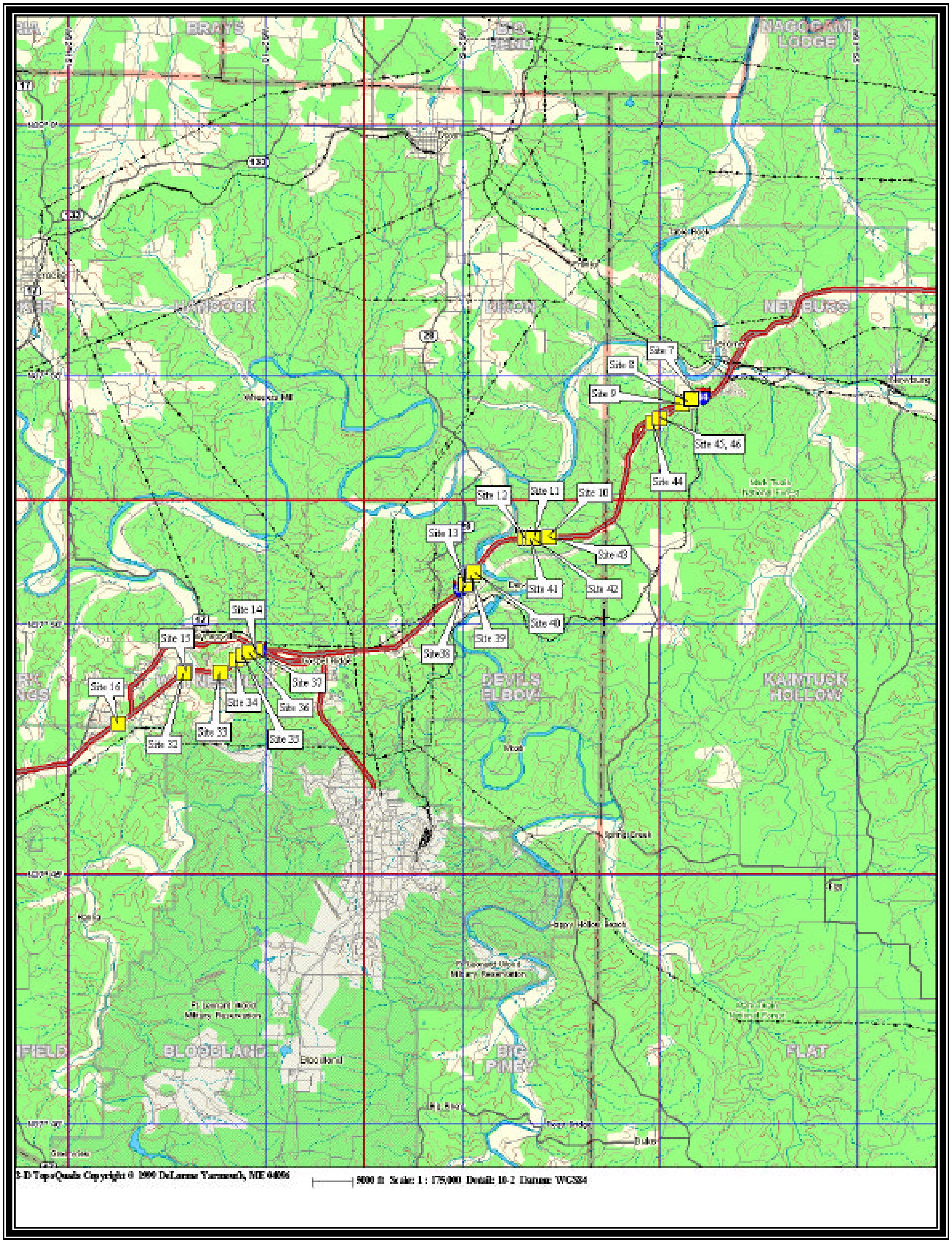


Figure 108b: Map 2 shows sites (7-16) and (32-46) for the rock cuts along Highway I-44.

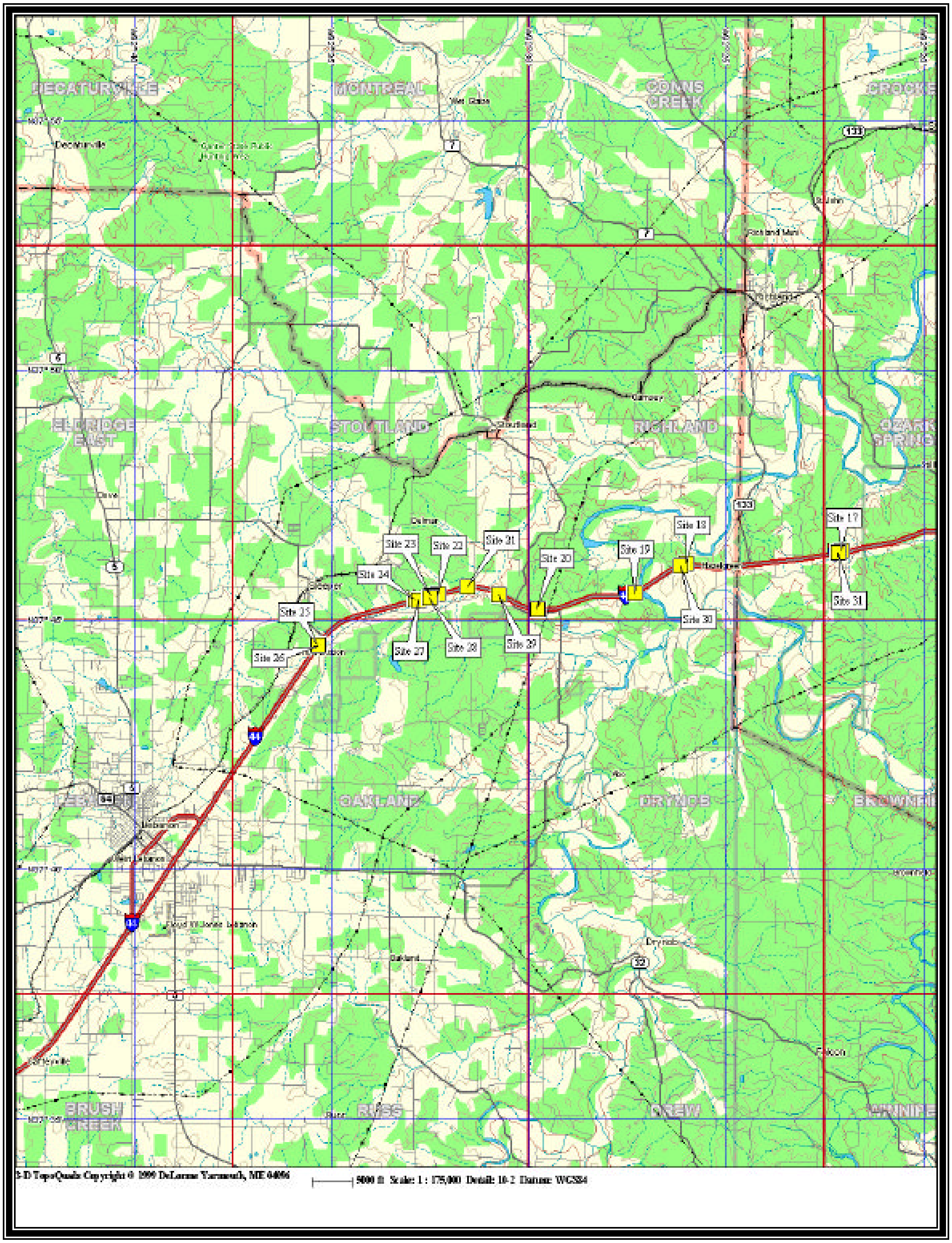


Figure 108c: Map 3 shows sites (17-31) for the rock cuts along Highway I-44.

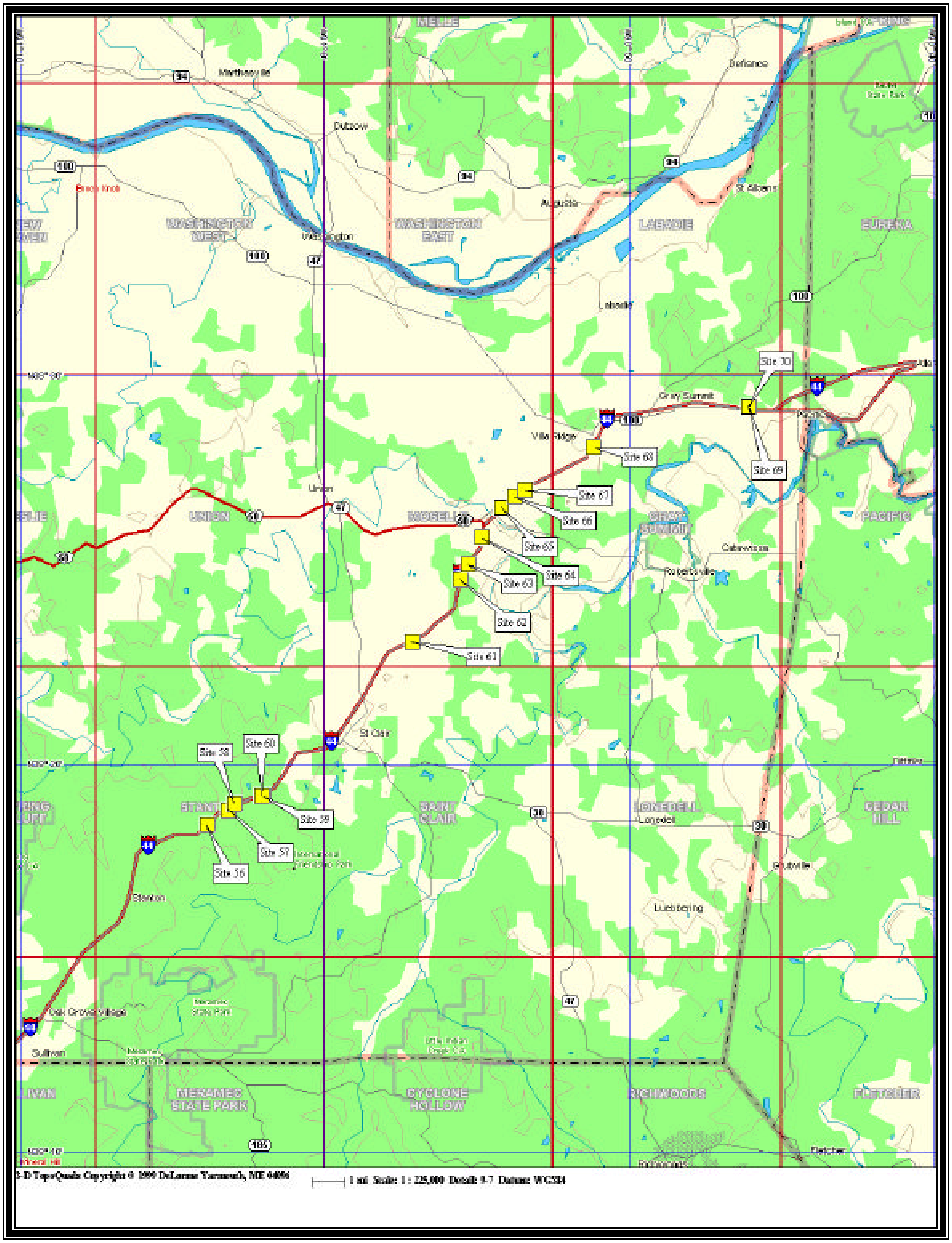


Figure 108d: Map 4 shows sites (56-70) for the rock cuts along Highway I-44.

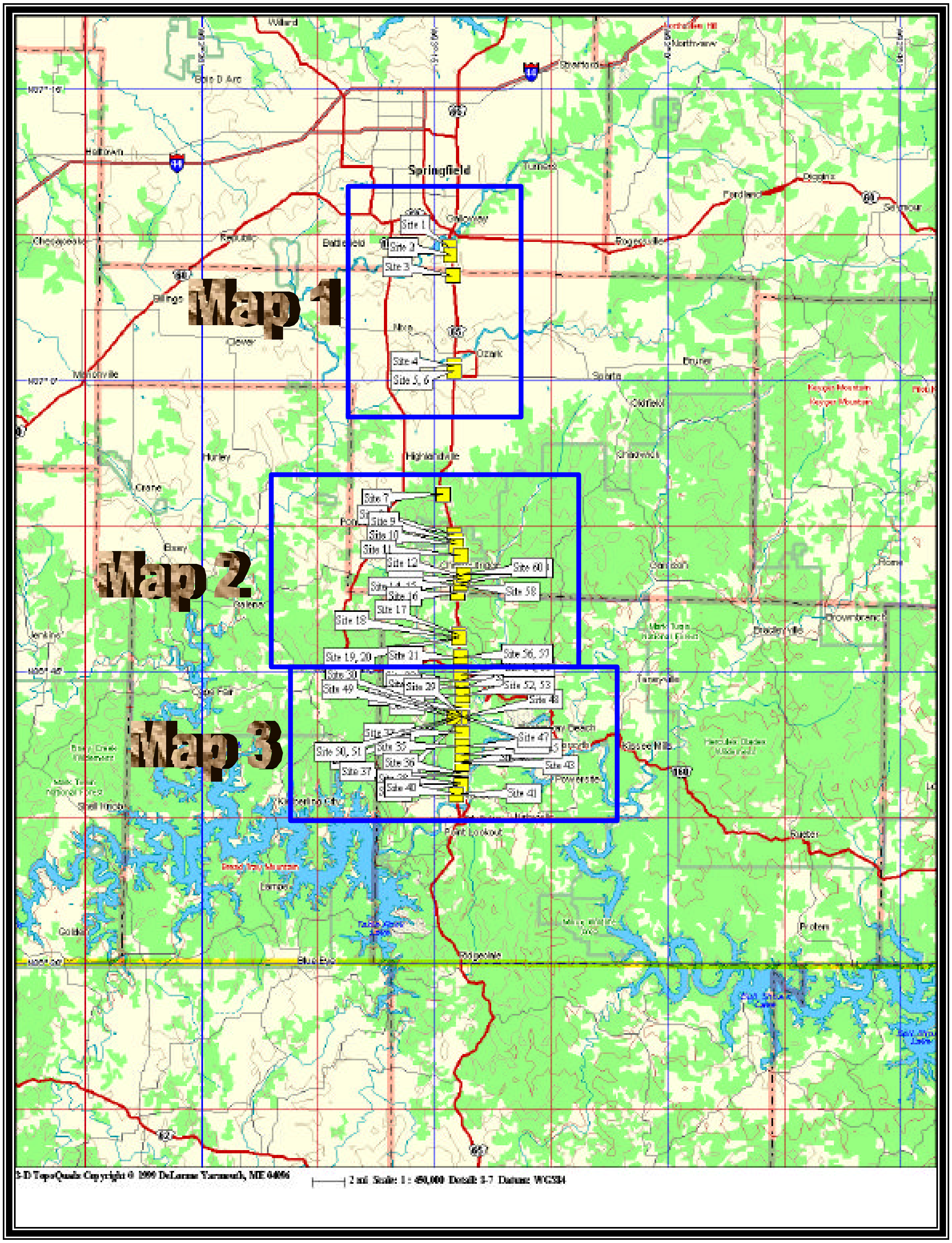


Figure 109: Map showing all sites along Highway 65.

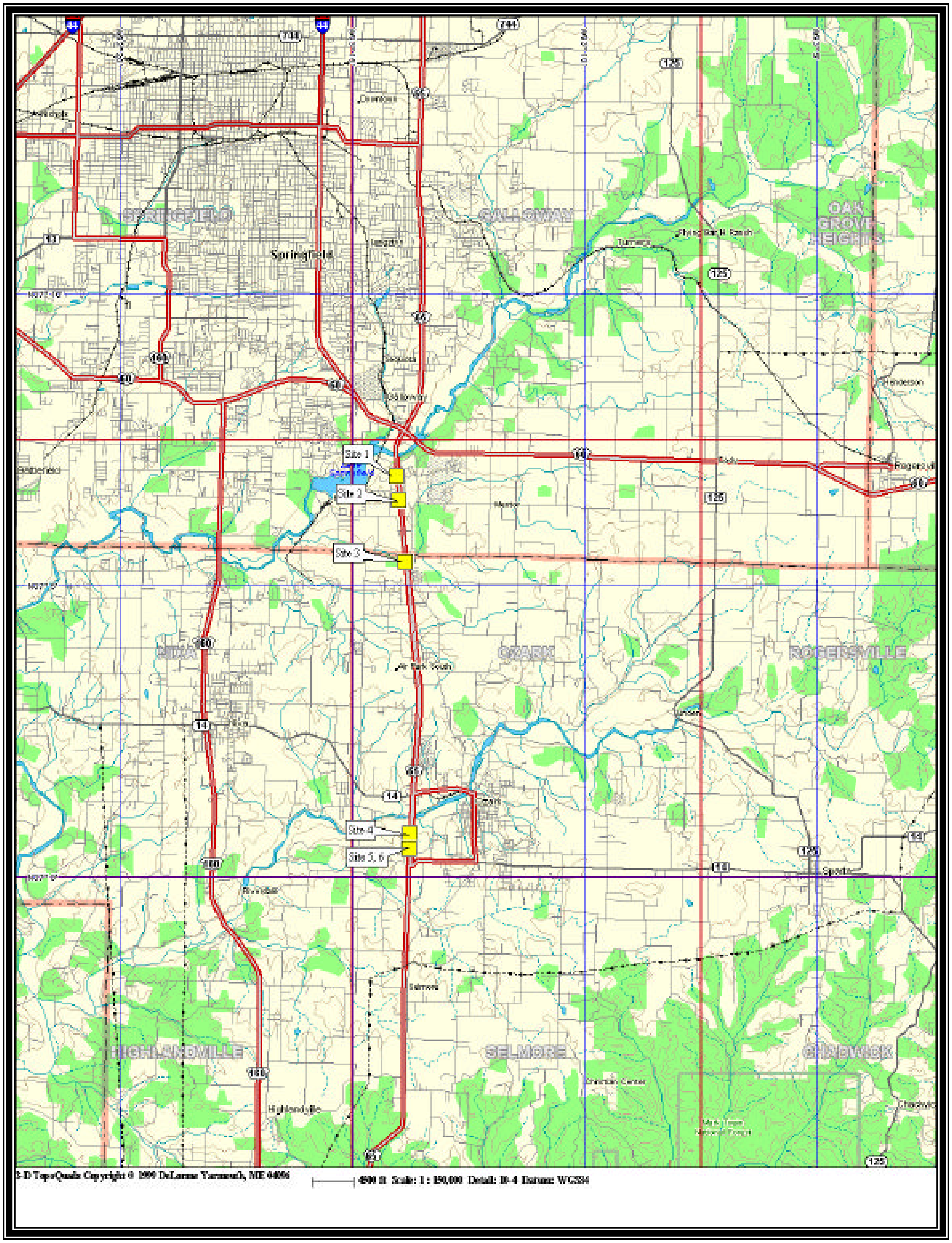


Figure 109a: Map 1 shows sites (1-6) for the rock cuts along Highway 65.

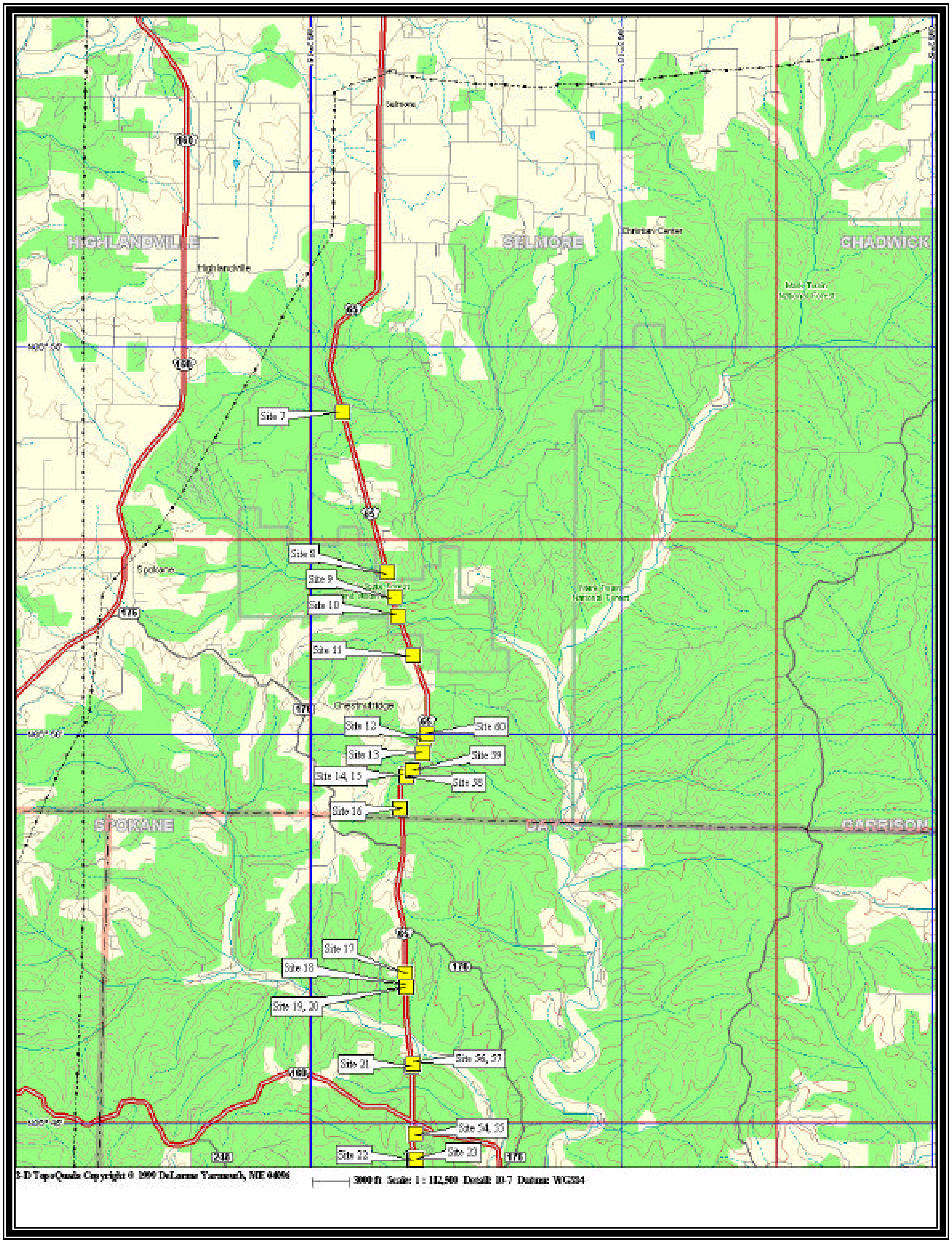


Figure 109b: Map 2 shows sites (7-21) and (56-60) for the rock cuts along Highway 65.

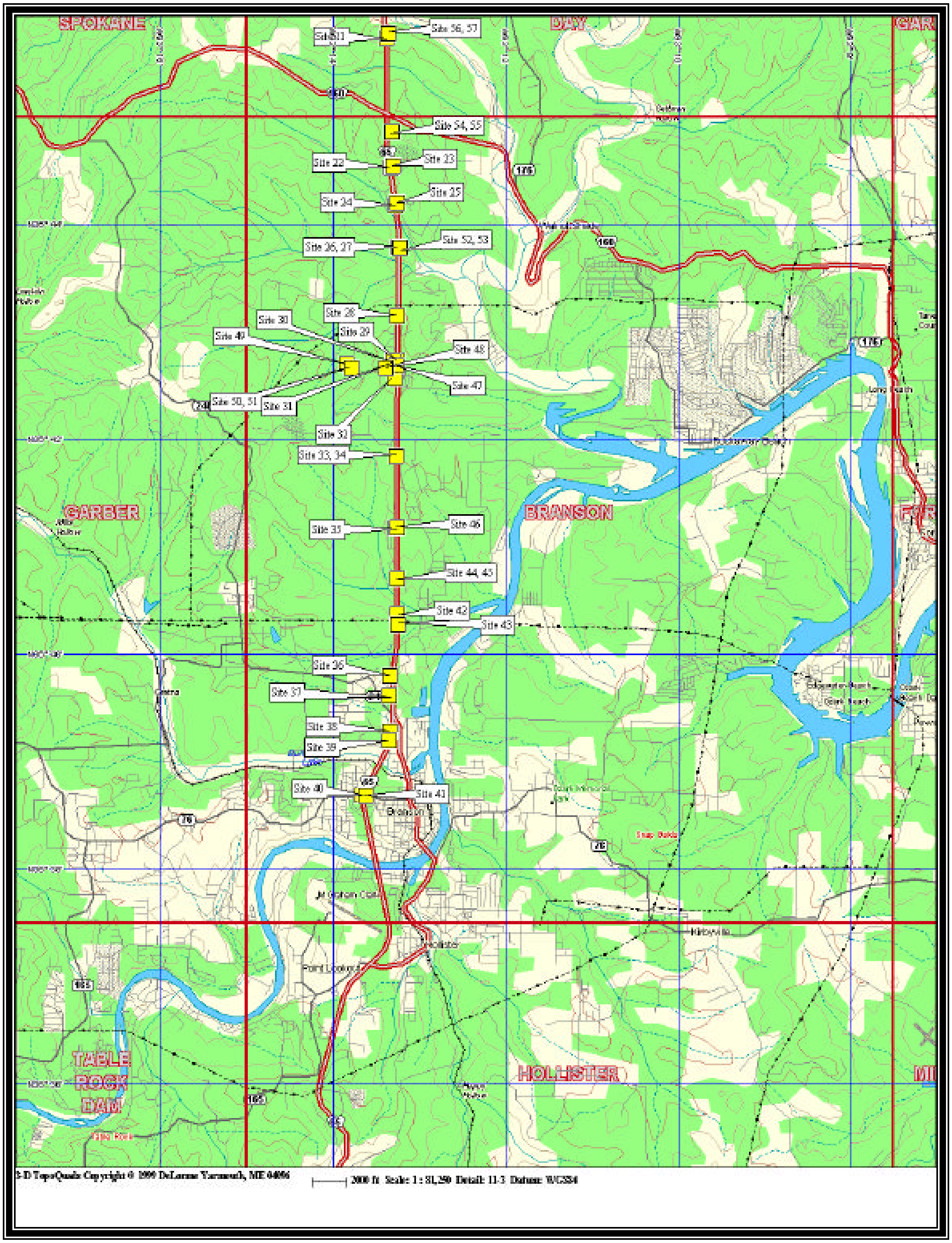


Figure 109c: Map 3 shows sites (22-55) for the rock cuts along Highway 65.

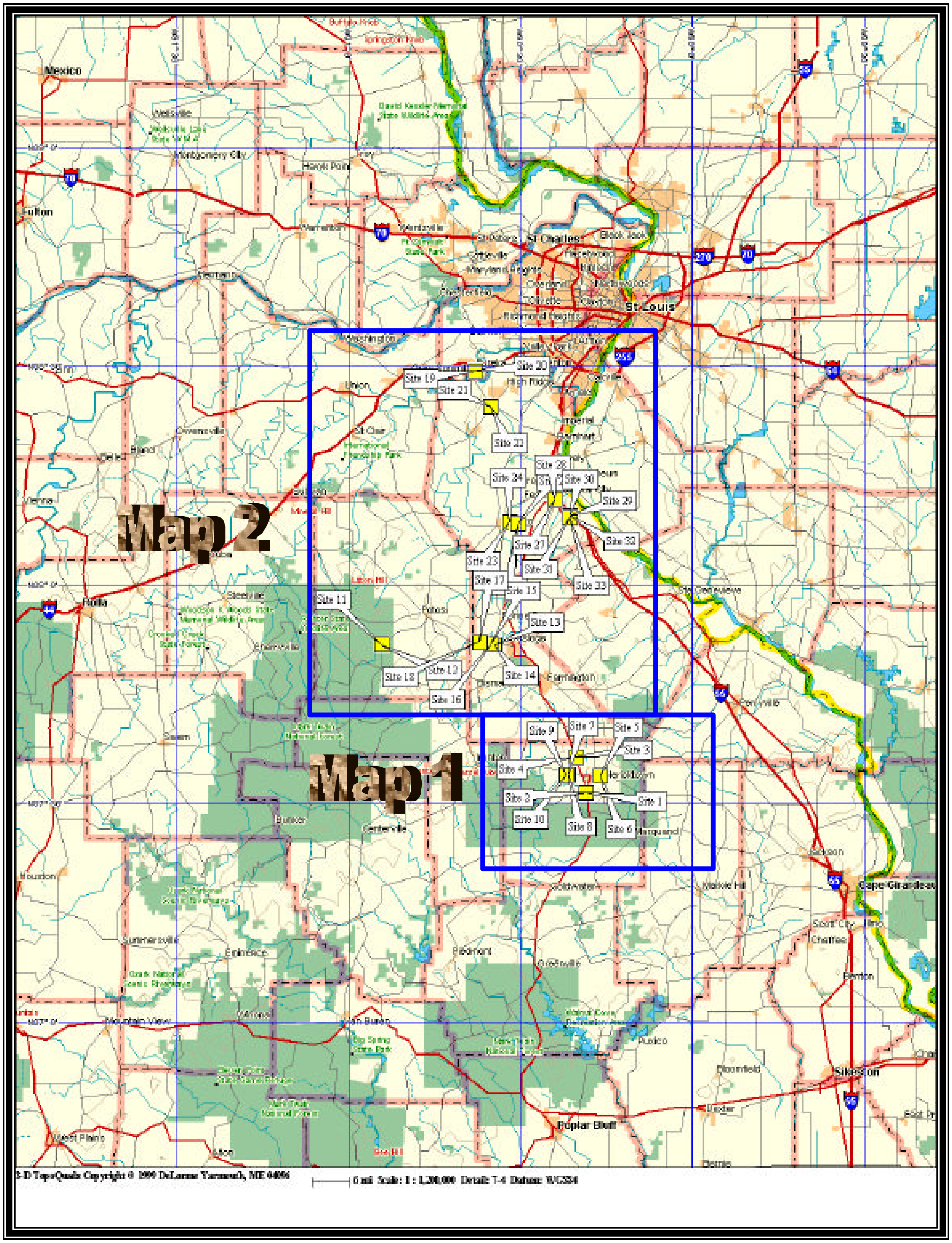


Figure 110: Map showing all sites along different Highways (67, 72, 8, 30, 110, 61, 55, exit from 67 to 55, and route W).

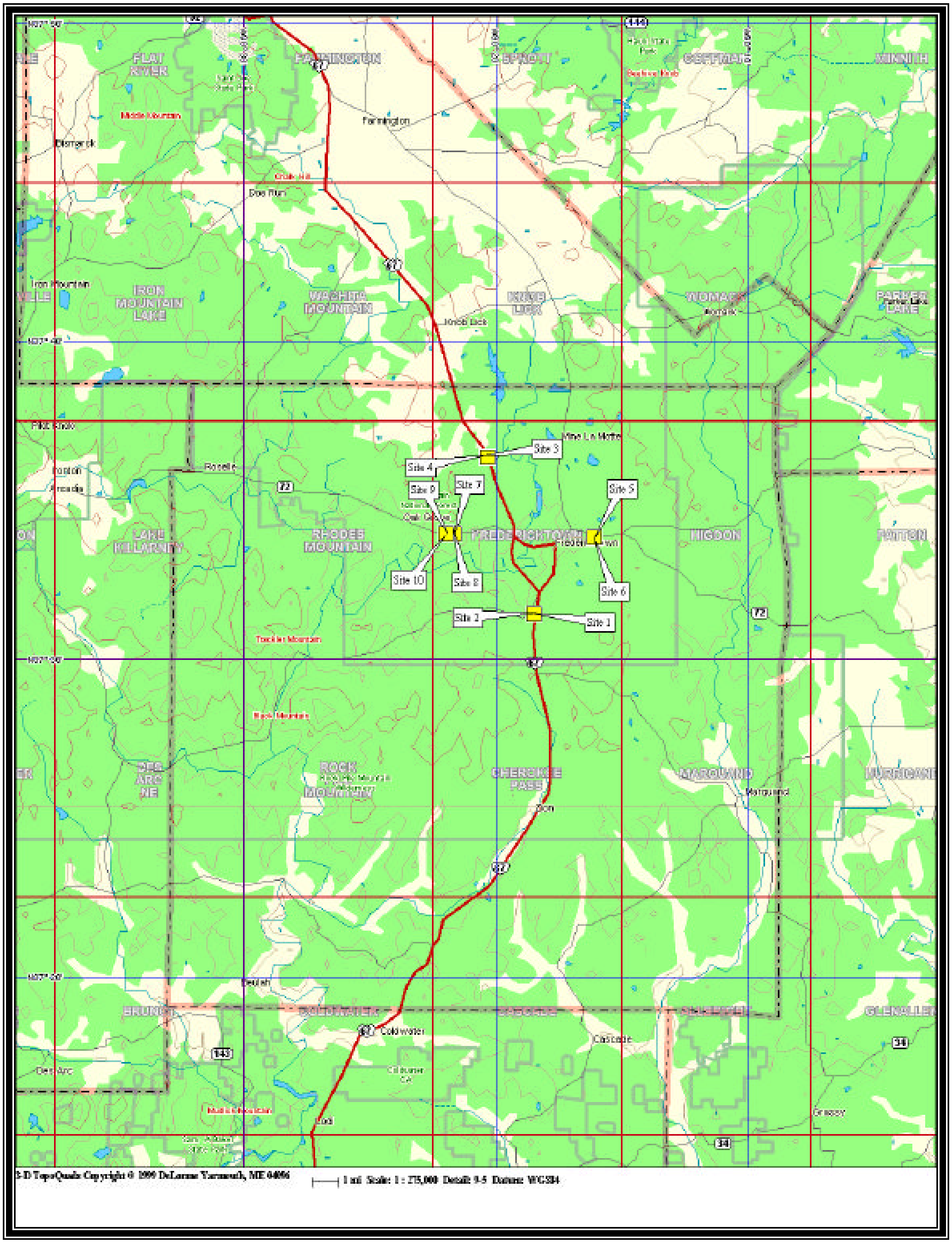


Figure 110a: Map 1 shows sites (1-10) for the rock cuts along Highways 67 and 72.

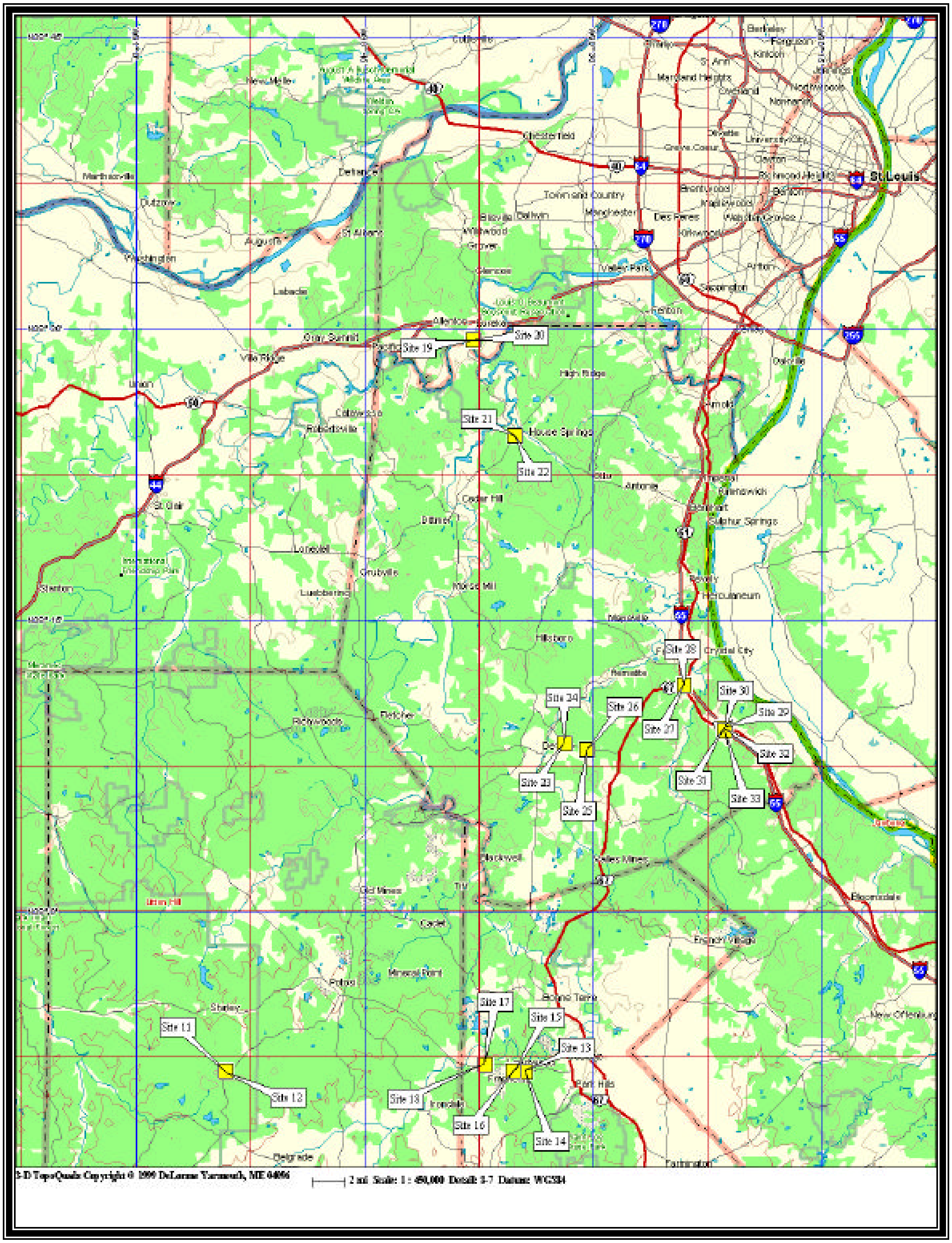


Figure 110b: Map 1 shows sites 11-33 for the rock cuts along Highways 8, 30, 110, 61, 5, exit from 67 to 55, and route W.

Table 20a: Data and rating values for Highway 63.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
1	63	N37-32.591	W91-51.745	30	6.0	65	7	4	12	3	18	0.5	10.5	4	12	4	12	5	0	2	6	0	0	0	0	69.6
2	63	N37-32.582	W91-51.756	30	6.0	65	7	4	12	3	18	0.5	10.5	4	12	4	12	4	1	2	6	0	0	0	0	70.0
3	63	N37-33.222	W91-51.749	20	4.0	65	7	4	12	2	12	1	9	3	9	4	12	5	0	1	3	0	0	0	0	56.7
4	63	N37-33.234	W91-51.762	20	4.0	60	6	4	12	3	18	0.5	10.5	4	12	4	12	5	0	2	6	0	0	0	0	67.1
5	63	N37-34.068	W91-51.751	30	6.0	90	12	2	6	2	12	2.5	4.5	3	9	3	9	4	1	1	3	0	0	0	0	51.7
6	63	N37-34.083	W91-51.761	30	6.0	90	12	2	6	3	18	2.5	4.5	3	9	3	9	4	1	1	3	0	0	0	0	56.7
7	63	N37-34.083	W91-51.762	10	2.0	90	12	3	9	2	12	1	9	4	12	3	9	4	1	2	6	1	4	0	0	62.9
8	63	N37-35.368	W91-51.766	20	4.0	90	12	3	9	2	12	0.5	10.5	4	12	3	9	5	0	2	6	0	0	0	0	62.1
9	63	N37-35.748	W91-51.751	30	6.0	80	10	4	12	3	18	1	9	4	12	4	12	4	1	2	6	2	8	0	0	77.9
10	63	N37-35.749	W91-51.761	40	8.0	90	12	4	12	3	18	1.5	7.5	4	12	4	12	5	0	2	6	2	8	0	0	79.6
11	63	N37-36.167	W91-51.755	25	5.0	90	12	4	12	3	18	1	9	4	12	4	12	5	0	2	6	0	0	0	0	71.7
12	63	N37-36.187	W91-51.765	20	4.0	90	12	3	9	2	12	2	6	3	9	3	9	5	0	2	6	0	0	0	0	55.8
13	63	N37-36.740	W91-51.760	30	6.0	50	4	3	9	2	12	1.5	7.5	2	6	3	9	2	5	1	3	0	0	0	0	50.8
14	63	N37-36.747	W91-51.770	30	6.0	50	4	3	9	2	12	1.5	7.5	2	6	3	9	2	5	1	3	0	0	0	0	50.8
15	63	N37-47.359	W91-50.253	30	6.0	90	12	1	3	1	6	3	3	1	3	1	3	4	1	2	6	0	0	0	0	35.4
16	63	N37-47.363	W91-50.285	30	6.0	90	12	1	3	1	6	3	3	1	3	1	3	4	1	1	3	0	0	0	0	32.9
17	63	N37-47.475	W91-49.544	15	3.0	70	8	2	6	2	12	1	9	2	6	2	6	1	8	1	3	0	0	0	0	50.8
18	63	N37-47.615	W91-49.315	40	8.0	80	10	1	3	0.5	3	3	3	1	3	1	3	4	1	2	6	0	0	0	0	32.9
19	63	N37-47.640	W91-49.311	15	3.0	80	10	1	3	1	6	3	3	1	3	1	3	4	1	0	0	0	0	0	0	26.2
20	63	N37-49.965	W91-47.833	9	1.8	90	12	4	12	3	18	1	9	3	9	4	12	3	2	1	3	0	0	0	0	65.6
21	63	N37-49.973	W91-47.839	9	1.8	90	12	3	9	3	18	0.5	10.5	3.5	10.5	3.5	10.5	3	2	1	3	0	0	0	0	64.4
22	63	N37-54.134	W91-46.820	10	2.0	90	12	3	9	3.5	21	1.5	7.5	3	9	3	9	2	5	1	3	0	0	0	0	64.1
23	63	N37-54.137	W91-46.831	12	2.4	90	12	3	9	3	18	1.5	7.5	3	9	3	9	1.5	6	1	3	0	0	0	0	63.3

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 20a: Data and rating values for Highway 63 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
1	9	8.4	1	4	12	7.2	65	3	9	3	1	12	5500	3.3	10	3	60	968	70	8.4	0	0	5	12.0	1	0	48.7
2	9	8.4	1	4	12	7.2	65	3	9	3	1	12	5500	3.3	20	6	60	968	70	8.4	0	0	4	8.1	1.7	3.3	51.4
3	9	8.8	1	4	12	7.2	65	3	9	3	1	12	5500	3.3	15	4.5	60	645	46.7	5.6	0	0	5	12.0	1.3	1.3	49.3
4	8	9.2	1	4	12	7.2	60	4	9	3	1	12	5500	3.3	30	9	60	726	52.5	6.3	0	0	5	12.0	2.5	7.5	60.5
5	7	6.4	-	0	7	9.2	90	0	9	3	1	12	5500	3.3	20	6	60	1210	87.5	11	0	0	4	8.1	2.9	9.3	58.0
6	6	7.2	-	0	6	9.6	90	0	9	3	1	12	5500	3.3	15	4.5	60	1210	87.5	11	0	0	4	8.1	2.5	7.5	56.0
7	9	4.8	-	0	12	7.2	90	0	9	3	1	12	5500	3.3	20	6	60	564	40.8	4.9	0	0	4	8.1	1.7	3.3	44.4
8	6	7.2	-	0	6	9.6	90	0	9	3	1	12	5500	3.3	20	6	60	645	46.7	5.6	0	0	5	12.0	3.3	12	60.6
9	6	9.6	1	4	6	9.6	80	9	9	3	1	12	5500	3.3	40	12	60	887	64.2	7.7	0	0	4	8.1	6.7	15	74.3
10	6	7.2	-	0	7	9.2	90	0	9	3	1	12	5500	3.3	30	9	60	564	40.8	4.9	0	0	5	12.0	4.3	15	65.5
11	9	4.8	-	0	12	7.2	90	0	9	3	1	12	5500	3.3	20	6	60	403	29.2	3.5	0	0	5	12.0	1.7	3.3	46.5
12	9	4.8	-	0	12	7.2	90	0	9	3	1	12	5500	3.3	10	3	60	887	64.2	7.7	0	0	5	12.0	1	0	44.2
13	6	9.6	1	4	6	9.6	50	7	9	3	1	12	5500	3.3	15	4.5	60	968	70	8.4	2	8	2	2.1	2.5	7.5	61.7
14	6	9.6	1	4	6	9.6	50	7	9	3	1	12	5500	3.3	15	4.5	60	887	64.2	7.7	2	8	2	2.1	2.5	7.5	61.2
15	18	0	-	0	24	2.4	90	0	12	0	1	12	5500	3.3	0	0	60	100	7.23	0.9	1	4	4	8.1	1	0	25.5
16	20	0	-	0	24	2.4	90	0	12	0	1	12	5500	3.3	5	1.5	60	100	7.23	0.9	0	0	4	8.1	1	0	23.5
17	12	7.2	1	4	24	2.4	70	2	9	3	1	12	5500	3.3	10	3	60	161	11.6	1.4	0	0	1	0.6	1	0	29.5
18	12	7.2	1	4	20	4	80	9	11	1	1	12	5500	3.3	5	1.5	60	100	7.23	0.9	0	0	4	8.1	1	0	38.6
19	12	7.2	1	4	24	2.4	80	9	11	1	1	12	5500	3.3	0	0	60	100	7.23	0.9	0	0	4	8.1	1	0	36.3
20	1	11	-	0	1	12	90	0	11	1	1	12	5500	3.3	10	3	60	242	17.5	2.1	1	4	3	4.6	10	15	59.0
21	1	11	-	0	1	12	90	0	12	0	1	12	5500	3.3	10	3	60	242	17.5	2.1	2	8	3	4.6	10	15	61.5
22	3	9.6	-	0	3	11	90	0	10	2	1	12	5500	3.3	15	4.5	60	242	17.5	2.1	1	4	2	2.1	5	15	57.0
23	2	10	-	0	4	10	90	0	12	0	1	12	5500	3.3	10	3	60	242	17.5	2.1	0	0	1.5	1.3	2.5	7.5	42.9

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 20b: Data and rating values for Highway 63.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Ris
4	63	N37-54.219	W91-46.674	12	2.4	90	12	3	9	2	12	2	6	2	6	2	6	2	5	1	3	0	0	0	0	50.7
25	63	N37-54.222	W91-46.681	8	1.6	90	12	3	9	1.5	9	1.5	7.5	2	6	3	9	1.5	6	1	3	0	0	0	0	52.7
26	63	N38-02.412	W91-46.601	20	4.0	90	12	4	12	3.5	21	1	9	3.5	10.5	3	9	1.5	6	1	3	0	0	1	3	75.2
27	63	N38-02.412	W91-46.549	17	3.4	90	12	4	12	3	18	1	9	4	12	3	9	2	5	2	6	0	0	1	3	74.6
28	63	N38-02.459	W91-46.608	30	6.0	90	12	1.5	4.5	2	12	2.5	4.5	1.5	4.5	2	6	1.5	6	2	6	0	0	1	3	54.4
29	63	N38-01.459	W91-46.599	50	10.0	80	10	4	12	4	24	0.5	10.5	4	12	4	12	4	1	2	6	2	8	4	12	100
30	63	N38-00.897	W91-46.547	30	6.0	90	12	3	9	3.5	21	1	9	3	9	4	12	4	1	1	3	0	0	1	3	70.9
31	63	N38-00.902	W91-46.539	20	4.0	90	12	3	9	2	12	2	6	2	6	3	9	2	5	1	3	0	0	1	3	57.6
32	63	N38-00.860	W91-46.531	25	5.0	90	12	4	12	4	24	0.5	10.5	3	9	4	12	5	0	1	3	0	0	1	3	75.9
33	63	N38-00.787	W91-46.533	9	1.8	90	12	2	6	1.5	9	2	6	1	3	4	12	5	0	1	3	0	0	1	3	47.0
34	63	N38-00.751	W91-46.517	20	4.0	90	12	3	9	3.5	21	1.5	7.5	3	9	3	9	3	2	2	6	0	0	1	3	69.2
35	63	N38-00.499	W91-46.502	30	6.0	90	12	2	6	2	12	2	6	1	3	2	6	2.5	3	2	6	0	0	1	3	53.1
36	63	N38-00.504	W91-46.494	30	6.0	90	12	4	12	4	24	0.5	10.5	2	6	4	12	5	0	2	6	0	0	3	9	82.8
37	63	N37-58.520	W91-45.620	25	5.0	90	12	3	9	3	18	2	6	2	6	3	9	3	2	1	3	0	0	1	3	61.3
38	63	N37-58.486	W91-45.601	25	5.0	90	12	4	12	4	24	0	12	3	9	3	9	4	1	1	3	0	0	1	3	75.1
39	63	N38-07.733	W91-48.296	32	6.4	90	12	3	9	2.5	15	2	6	2	6	2	6	4	1	1	3	0	0	1	3	56.3
40	63	N38-07.701	W91-48.216	22	4.4	90	12	3	9	3	18	0.5	10.5	2.5	7.5	3	9	3	2	1	3	0	0	1	3	65.8
41	63	N38-07.717	W91-48.279	36	7.2	90	12	4	12	3	18	2	6	3	9	4	12	4	1	1	3	0	0	2	6	72.4
42	63	N38-07.752	W91-48.388	15	3.0	90	12	3	9	3	18	1.5	7.5	2	6	3	9	2	5	1	3	0	0	1	3	63.0
43	63	N38-07.795	W91-48.559	40	8.0	90	12	2	6	1.5	9	2.5	4.5	1	3	2	6	4	1	2	6	0	0	1	3	48.8
44	63	N38-07.764	W91-48.480	33	6.6	90	12	4	12	4	24	1	9	4	12	4	12	4	1	2	6	0	0	3	9	87.4
45	63	N38-07.858	W91-48.830	25	5.0	90	12	2	6	1.5	9	3	3	1	3	2	6	2	5	2	6	0	0	1	3	48.4
46	63	N38-07.837	W91-48.796	23	4.6	90	12	4	12	3.5	21	0	12	2	6	3	9	4	1	2	6	0	0	2	6	75.2

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering,
SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face,
DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 20b: Data and rating values for Highway 63 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
24	1	11	-	0	1	12	90	0	11	1	1	12	5500	3.3	5	1.5	60	484	35	4.2	0	0	2	2.1	5	15	54.1
25	2	10	-	0	2	11	90	0	11	1	1	12	5500	3.3	5	1.5	60	484	35	4.2	0	0	1.5	1.3	2.5	7.5	44.9
26	9	4.8	-	0	9	8.4	90	0	12	0	1	12	5500	3.3	20	6	65	242	16.2	1.9	0	0	1.5	1.3	2.2	6.1	37.5
27	9	4.8	-	0	18	4.8	90	0	12	0	1	12	5500	3.3	25	7.5	65	202	13.5	1.6	0	0	2	2.1	1.4	1.9	32.1
28	9	4.8	-	0	12	7.2	90	0	12	0	1	12	5500	3.3	10	3	65	100	6.68	0.8	0	0	1.5	1.3	1	0	27.0
29	6	9.6	3	12	3	11	80	9	20	0	1	12	5500	3.3	100	12	65	700	46.7	5.6	1	4	4	8.0	33	15	83.4
30	10	4	-	0	18	4.8	90	0	12	0	1	12	5500	3.3	30	9	65	322	21.5	2.6	0	0	4	8.1	1.7	3.3	39.8
31	9	4.8	-	0	12	7.2	90	0	12	0	1	12	5500	3.3	10	3	65	200	13.4	1.6	0	0	2	2.1	1	0	28.4
32	9	4.8	-	0	18	4.8	90	0	12	0	1	12	5500	3.3	40	12	65	282	18.8	2.3	0	0	5	12.0	2.2	6.1	48.7
33	12	2.4	-	0	18	4.8	90	0	12	0	1	12	5500	3.3	10	3	65	242	16.2	1.9	0	0	5	12.0	1	0	32.9
34	12	2.4	-	0	18	4.8	90	0	12	0	1	12	5500	3.3	15	4.5	65	645	43.1	5.2	0	0	3	4.6	1	0	30.7
35	9	4.8	-	0	12	7.2	90	0	12	0	1	12	5500	3.3	5	1.5	65	100	6.68	0.8	0	0	2.5	3.3	1	0	27.4
36	9	4.8	-	0	12	7.2	90	0	12	0	1	12	5500	3.3	50	12	65	200	13.4	1.6	0	0	5	12.0	4.2	15	59.1
37	8	5.6	-	0	18	4.8	90	0	12	0	2	6	5500	3.3	20	6	65	806	26.9	3.2	0	0	3	4.6	1.1	0.6	28.5
38	9	4.8	-	0	18	4.8	90	0	12	0	2	6	5500	3.3	40	12	65	968	32.3	3.9	0	0	4	8.1	2.2	6.1	41.8
39	16	0	-	0	24	2.4	90	0	13	0	1	12	5500	3.3	40	12	65	420	28	3.4	0	0	4	8.1	1.7	3.3	37.6
40	16	0	-	0	24	2.4	90	0	13	0	2	6	5500	3.3	15	4.5	65	120	4.01	0.5	0	0	3	4.6	1	0	17.8
41	18	0	-	0	27	1.2	90	0	13	0	2	6	5500	3.3	90	12	65	100	3.34	0.4	0	0	4	8.1	3.3	12	37.5
42	15	0	-	0	24	2.4	90	0	14	0	1	12	5500	3.3	15	4.5	65	430	28.7	3.4	0	0	2	2.1	1	0	23.2
43	12	2.4	-	0	12	7.2	90	0	14	0	1	12	5500	3.3	5	1.5	60	50	3.62	0.4	0	0	4	8.1	1	0	29.1
44	12	2.4	-	0	18	4.8	90	0	13	0	2	6	5500	3.3	90	12	65	1200	40.1	4.8	0	0	4	8.1	5	15	49.5
45	15	0	-	0	25	2	90	0	14	0	1	12	5500	3.3	5	1.5	65	50	3.34	0.4	0	0	2	2.1	1	0	17.8
46	14	0.8	-	0	20	4	90	0	13	0	2	6	5500	3.3	80	12	65	600	20	2.4	0	0	4	8.1	4	15	45.5

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 20c: Data and rating values for Highway 63.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
47	63	N38-07.990	W91-49.489	40	8.0	90	12	4	12	3.5	21	1	9	3.5	10.5	3.5	10.5	1.5	6	2	6	3	12	4	12	100
48	63	N38-07.979	W91-49.538	37	7.4	90	12	4	12	3	18	1	9	3	9	4	12	5	0	1	3	0	0	3	9	77.7
49	63	N38-07.646	W91-51.163	42	8.4	90	12	3.5	10.5	3.5	21	1.5	7.5	3	9	3	9	4	1	3	9	0	0	1	3	75.4
50	63	N38-07.646	W91-51.163	32	6.4	90	12	4	12	4	24	0	12	2.5	7.5	3.5	10.5	3	2	0	0	0	0	1	3	75.0
51	63	N38-07.705	W91-51.314	30	6.0	90	12	4	12	3.5	21	0.5	10.5	2.5	7.5	3	9	4.5	0	1	3	0	0	2	6	73.6
52	63	N38-07.705	W91-51.314	30	6.0	90	12	3	9	3	18	1	9	1.5	4.5	3	9	4	1	2	6	0	0	1	3	64.7
53	63	N38-07.843	W91-51.563	22	4.4	90	12	3	9	3.5	21	0	12	2.5	7.5	3.5	10.5	3	2	2	6	0	0	1	3	73.3
54	63	N38-07.843	W91-51.563	23	4.6	90	12	2	6	3	18	1	9	2	6	2	6	2	5	1	3	0	0	1	3	60.6
55	63	N38-08.835	W91-53.069	35	7.0	90	12	1.5	4.5	2	12	2	6	1.5	4.5	3	9	3	2	2	6	0	0	1	3	55.5
56	63	N38-08.835	W91-53.069	45	9.0	90	12	2.5	7.5	3	18	2	6	2.5	7.5	3	9	1.5	6	1.5	4.5	0	0	1	3	69.4
57	63	N38-08.974	W91-53.517	45	9.0	90	12	4	12	4	24	1	9	3.5	10.5	3.5	10.5	2	5	1	3	3	12	4	12	100
58	63	N38-08.974	W91-53.517	45	9.0	90	12	4	12	4	24	0	12	4	12	4	12	5	0	1	3	0	0	3	9	89.0
59	63	N38-21.254	W91-55.273	12	2.4	90	12	4	12	4	24	1	9	4	12	4	12	1	8	1	3	0	0	1	3	81.6
60	63	N38-21.254	W91-55.273	10	2.0	75	9	4	12	4	24	1	9	3	9	4	12	1	8	1	3	0	0	1	3	76.3
61	63	N38-21.891	W91-55.657	12	2.4	75	9	4	12	4	24	1	9	4	12	4	12	2	5	1	3	0	0	1	3	76.2
62	63	N38-23.270	W91-55.860	10	2.0	90	12	3	9	3	18	2	6	3	9	3	9	1	8	1	3	0	0	1	3	66.3
63	63	N38-23.270	W91-55.860	8	1.6	75	9	4	12	4	24	1.5	7.5	2	6	3	9	2	5	1	3	0	0	1	3	66.8
64	63	N38-23.413	W91-55.992	10	2.0	90	12	4	12	4	24	1.5	7.5	3	9	3	9	2	5	1	3	0	0	1	3	72.1
65	63	N38-23.413	W91-55.992	10	2.0	75	9	3	9	3	18	2	6	2	6	3	9	2	5	1	3	0	0	1	3	58.4
66	63	N38-25.410	W91-58.890	20	4.0	90	12	3	9	4	24	0.5	10.5	4	12	3.5	10.5	1	8	2	6	0	0	1	3	83.0
67	63	N38-25.484	W91-58.980	20	4.0	90	12	2	6	0.5	3	3	3	0.5	1.5	2	6	3	2	2	6	0	0	1	3	39.2
68	63	N38-25.544	W91-59.017	50	10.0	90	12	3.5	10.5	3.5	21	1.5	7.5	3	9	3	9	1.5	6	3	9	0	0	1	3	81.5
69	63	N38-25.410	W91-58.890	35	7.0	90	12	4	12	4	24	1	9	4	12	4	12	2	5	3	9	0	0	1	3	87.6

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering,
SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face,
DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 20c: Data and rating values for Highway 63 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
47	13	1.6	-	0	20	4	90	0	13	0	1	12	5500	3.3	100	12	65	750	50.1	6.01	1	4	1.5	1.3	5	15	51.8
48	12	2.4	-	0	18	4.8	90	0	14	0	1	12	5500	3.3	100	12	65	650	43.4	5.2	2	8	5	12.0	5.6	15	64.7
49	18	0	-	0	18	4.8	90	0	14	0	1	12	5500	3.3	30	9	65	530	35.4	4.2	1	4	4	8.1	1.7	3.3	41.2
50	18	0	-	0	18	4.8	90	0	13	0	1	12	5500	3.3	30	9	65	530	35.4	4.2	1	4	3	4.6	1.7	3.3	38.3
51	16	0	-	0	24	2.4	90	0	13	0	1	12	5500	3.3	60	12	65	300	20	2.4	1.5	6	4.5	10.1	2.5	7.5	47.6
52	16	0	-	0	24	2.4	90	0	13	0	1	12	5500	3.3	30	9	65	300	20	2.4	0	0	4	8.1	1.3	1.3	32.2
53	14	0.8	-	0	35	0	90	0	12	0	1	12	5500	3.3	40	12	65	300	20	2.4	0	0	3	4.6	1.1	0.7	30.0
54	16	0	-	0	32	0	90	0	13	0	2	6	5500	3.3	10	3	65	300	10	1.2	0	0	2	2.1	1	0	13.0
55	18	0	-	0	36	0	90	0	13	0	1	12	5500	3.3	30	9	65	500	33.4	4	0	0	3	4.6	1	0	27.4
56	13	1.6	-	0	13	6.8	90	0	15	0	1	12	5500	3.3	45	12	65	500	33.4	4.01	0	0	1.5	1.3	3.5	12	46.5
57	13	1.6	-	0	8	8.8	90	0	16	0	2	6	5500	3.3	150	12	65	500	16.7	2	1	4	2	2.1	19	15	48.2
58	13	1.6	-	0	13	6.8	90	0	16	0	1	12	5500	3.3	100	12	65	500	33.4	4	0	0	5	12.0	7.7	15	58.1
59	3	9.6	-	0	1.5	11	90	0	2	10	1	12	6000	3.6	10	3	65	200	14.6	1.7	1	4	1	0.6	6.7	15	61.7
60	3	11	3	12	1.5	11	75	4.5	2	10	1	12	6000	3.6	10	3	65	200	14.6	1.7	1	4	1	0.6	6.7	15	70.8
61	2	11	3	12	1	12	75	4.5	3	9	1	12	6000	3.6	6	1.8	65	150	10.9	1.3	1	4	2	2.1	6	15	70.4
62	4	8.8	-	0	4	10	90	0	4	8	1	12	6000	3.6	5	1.5	65	150	10.9	1.3	1	4	1	0.6	1.3	1.3	43.1
63	3	11	1	4	3	11	75	4.5	4	8	1	12	6000	3.6	10	3	65	150	10.9	1.3	1	4	2	2.1	3.3	12	60.3
64	1	11	-	0	0.5	12	90	0	3	9	1	12	6000	3.6	18	5.4	60	200	15.8	1.9	1	4	2	2.1	36	15	65.9
65	2	11	2	8	1	12	75	4.5	2	10	1	12	6000	3.6	5	1.5	65	200	14.6	1.7	1	4	2	2.1	5	15	68.2
66	30	0	-	0	30	0	90	0	12	0	1	12	6000	3.6	45	12	65	250	18.2	2.2	0	0	1	0.6	1.5	2.5	27.9
67	30	0	-	0	45	0	90	0	12	0	1	12	6000	3.6	5	1.5	65	300	21.9	2.6	0	0	3	4.6	1	0	20.3
68	30	0	1	4	45	0	90	0	12	0	1	12	6000	3.6	40	12	65	400	29.1	3.5	0	0	1.5	1.3	1	0	27.5
69	21	3.6	2	6	30	0	90	0	8	4	2	6	6000	3.6	60	12	65	400	14.6	1.7	0	0	2	2.1	2	5	34.6

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 20d: Data and rating values for Highway 63.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Ris
70	63	N38-25.484	W91-58.980	30	6.0	90	12	3	9	4	24	1	9	3.5	10.5	3.5	10.5	2	5	2	6	0	0	1	3	79.2
71	63	N38-25.544	W91-59.017	50	10.0	90	12	2.5	7.5	2.5	15	1.5	7.5	2	6	3	9	1.5	6	1	3	0	0	1	3	66.5
72	63	N38-25.788	W91-59.223	35	7.0	90	12	4	12	4	24	1	9	3.5	10.5	4	12	2	5	2	6	0	0	1	3	83.8
73	63	N38-27.687	W92-00.268	8	1.6	90	12	4	12	4	24	1	9	3	9	3	9	3	2	1	3	0	0	1	3	71.0
74	63	N38-31.587	W92-03.399	30	6.0	85	11	4	12	4	24	1	9	2	6	4	12	1.5	6	3	9	0	0	1	3	82.3
75	63	N38-31.587	W92-03.399	30	6.0	85	11	4	12	4	24	0.5	10.5	2.5	7.5	4	12	3	2	2	6	0	0	1	3	78.8
76	63	N38-32.267	W92-05.057	45	9.0	75	9	4	12	4	24	0.5	10.5	4	12	4	12	4	1	3	9	0	0	3	9	90.7
77	63	N38-32.393	W92-06.015	35	7.0	90	12	2	6	1	6	3	3	1	3	3	9	1	8	0	0	0	0	1	3	48.0
78	63	N38-32.393	W92-06.015	32	6.4	80	10	4	12	4	24	0.5	10.5	4	12	4	12	2	5	2	6	0	0	1	3	84.2
79	63	N38-32.539	W92-07.013	20	4.0	90	12	3	9	3.5	21	1.5	7.5	3	9	4	12	4.5	0	2	6	0	0	1	3	70.2
80	63	N38-32.539	W92-07.013	32	6.4	90	12	3.5	10.5	3.5	21	1	9	2	6	2	6	1	8	1	3	0	0	1	3	71.2
81	63	N38-32.779	W92-07.989	23	4.6	85	11	4	12	4	24	1	9	4	12	4	12	2	5	1	3	0	0	1	3	79.7
82	63	N38-32.779	W92-07.989	25	5.0	90	12	4	12	4	24	1	9	4	12	4	12	3	2	2	6	0	0	1	3	81.3
83	63	N38-32.779	W92-07.989	25	5.0	80	10	4	12	4	24	1	9	4	12	4	12	1.5	6	1	3	0	0	1	3	80.6
84	63	N38-38.510	W92-11.965	40	8.0	90	12	3	9	4	24	1	9	2	6	4	12	1.5	6	0	0	0	0	1	3	74.8
85	63	N38-40.217	W92-13.975	35	7.0	90	12	4	12	4	24	0.5	10.5	2	6	4	12	5	0	1	3	0	0	1	3	75.1
86	63	N38-40.267	W92-14.073	60	12.0	90	12	4	12	4	24	0.5	10.5	4	12	4	12	5	0	1.5	4.5	0	0	3	9	91.5
87	63	N38-40.267	W92-14.073	25	5.0	90	12	4	12	4	24	1	9	4	12	4	12	4	1	1	3	0	0	2	6	80.6
88	63	N38-40.646	W92-14.858	32	6.4	90	12	3	9	3	18	2	6	2	6	3	9	2	5	1	3	0	0	1	3	64.6
89	63	N38-40.646	W92-14.858	30	6.0	80	10	4	12	2.5	15	2	6	2	6	3	9	1	8	1	3	0	0	1	3	65.5
90	63	N38-40.687	W92-15.001	55	11.0	90	12	2	6	2	12	2.5	4.5	1	3	2	6	2	5	0	0	0	0	1	3	52.2
91	63	N38-40.687	W92-15.001	40	8.0	8	0	4	12	4	24	0.5	10.5	4	12	4	12	2	5	1	3	0	0	1	3	74.7
92	63	N38-40.863	W92-15.203	20	4.0	90	12	4	12	4	24	1	9	3	9	4	12	1	8	1	3	0	0	1	3	80.5

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 20d: Data and rating values for Highway 63 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
70	18	0	-	0	18	4.8	90	0	8	4	2	6	6000	3.6	45	12	65	300	10.9	1.3	0	0	2	2.1	2.5	7.5	35.7
71	21	3.6	2	6	30	0	90	0	8	4	2	6	6000	3.6	80	12	65	400	14.6	1.7	0	0	1.5	1.3	2.7	8.3	37.3
72	20	4	2	6	30	0	90	0	8	4	2	6	6000	3.6	50	12	65	300	10.9	1.3	2	8	2	2.1	1.7	3.3	39.0
73	4	8.8	-	0	2	11	90	0	3	9	1	12	6000	3.6	10	3	65	100	7.28	0.9	2	8	3	4.6	5	15	65.9
74	21	3.6	2	8	30	0	85	12	10	2	2	6	10000	6	40	12	65	300	18.2	2.2	0	0	1.5	1.3	1.3	1.7	41.9
75	22	3.2	2	6	44	0	85	12	12	0	2	6	10000	6	100	12	65	300	18.2	2.2	1	4	3	4.6	2.3	6.4	48.8
76	25	2	2	6	37	0	75	4.5	10	2	2	6	10000	6	150	12	65	600	36.4	4.4	1	4	4	8.1	4.1	15	56.6
77	20	0	-	0	35	0	90	0	12	0	2	6	10000	6	5	1.5	65	300	18.2	2.2	0	0	1	0.6	1	0	13.6
78	13	6.8	2	8	20	4	80	9	12	0	2	6	10000	6	40	12	65	300	18.2	2.2	0	0	2	2.1	2	5	47.5
79	15	0	-	0	20	4	90	0	12	0	2	6	10000	6	20	6	65	200	12.1	1.5	0	0	4.5	10.1	1	0	27.9
80	20	0	-	0	30	0	90	0	12	0	2	6	10000	6	30	9	65	500	30.4	3.64	0	0	1	0.6	1	0	21.1
81	13	6.8	2	8	13	6.8	85	12	12	0	2	6	10000	6	60	12	65	300	18.2	2.2	0	0	2	2.1	4.6	15	61.9
82	16	0	-	0	24	2.4	90	0	12	0	2	6	10000	6	60	12	65	300	18.2	2.2	0	0	3	4.6	2.5	7.5	35.2
83	15	6	2	6	15	6	80	9	12	0	2	6	10000	6	80	12	65	500	30.4	3.6	1	4	1.5	1.3	5.3	15	60.4
84	23	0	-	0	33	0	90	0	12	0	2	6	17000	10.2	30	9	70	200	19.2	2.3	0	0	1.5	1.3	1	0	24.0
85	22	0	-	0	22	3.2	90	0	12	0	2	6	17000	10.2	120	12	70	200	19.2	2.3	0	0	5	12.0	5.5	15	53.1
86	20	0	-	0	15	6	90	0	10	2	2	6	17000	10.2	500	12	70	450	43.1	5.2	0	0	5	12.0	33	15	59.5
87	17	0	-	0	25	2	90	0	10	2	2	6	17000	10.2	100	12	70	350	33.5	4	0	0	4	8.1	4	15	51.9
88	19	0	-	0	30	0	90	0	12	0	2	6	17000	10.2	30	9	70	250	24	2.9	0	0	2	2.1	1	0	25.2
89	13	6.8	2	6	20	4	80	9	10	2	2	6	17000	10.2	20	6	70	250	24	2.9	0	0	1	0.6	1	0	40.5
90	19	0	-	0	30	0	90	0	12	0	2	6	17000	10.2	15	4.5	70	300	28.7	3.4	0	0	2	2.1	1	0	21.9
91	14	6.4	2	8	14	6.4	80	9	10	2	2	6	17000	10.2	140	12	70	250	24	2.9	1	4	2	2.1	10	15	67.3
92	17	0	-	0	25	2	90	0	12	0	2	6	17000	10.2	20	6	70	150	14.4	1.7	1.5	6	1	0.6	1	0	27.1

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 20e: Data and rating values for Highway 63.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
93	63	N38-41.130	W92-15.297	40	8.0	90	12	4	12	4	24	0.5	10.5	3	9	4	12	5	0	2	6	0	0	1	3	80.9
94	63	N38-41.130	W92-15.297	50	10.0	75	9	4	12	3	18	2	6	2	6	4	12	2	5	1	3	0	0	1	3	70.1
95	63	N38-41.229	W92-15.297	30	6.0	90	12	4	12	4	24	0.5	10.5	2	6	3	9	5	0	2	6	0	0	1	3	74.3
96	63	N38-41.229	W92-15.297	12	2.4	90	12	3	9	2	12	2	6	2	6	3	9	1	8	1	3	0	0	1	3	59.1
97	63	N38-41.396	W92-15.291	20	4.0	90	12	4	12	4	24	0.5	10.5	3	9	4	12	2.5	3	2	6	0	0	1	3	80.2
98	63	N38-41.817	W92-15.281	8	1.6	90	12	2	6	2	12	2	6	1	3	2	6	2	5	0	0	0	0	1	3	45.6
99	63	N38-42.055	W92-15.302	15	3.0	90	12	4	12	4	24	1	9	4	12	4	12	4	1	1	3	0	0	1	3	75.9
100	63	N38-42.416	W92-15.294	25	5.0	90	12	3	9	1.5	9	3	3	1	3	3	9	3	2	2	6	0	0	1	3	51.3
101	63	N38-41.229	W92-15.297	20	4.0	90	12	3.5	10.5	2	12	2	6	4	12	4	12	3	2	0	0	0	0	1	3	61.7

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 20e: Data and rating values for Highway 63 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
93	20	0	-	0	15	6	90	0	12	0	2	6	17000	10	160	12	70	300	28.7	3.45	2	8	5	12.0	11	15	63.0
94	15	6	1.5	6	15	6	75	4.5	10	2	2	6	17000	10	20	6	70	300	28.7	3.45	1	4	2	2.1	1.3	1.7	44.3
95	19	0	-	0	15	6	90	0	12	0	2	6	17000	10	45	12	70	400	38.3	4.6	0	0	5	12.0	3	10	52.3
96	10	4	-	0	5	10	90	0	12	0	2	6	17000	10	10	3	70	300	28.7	3.45	0	0	1	0.6	2	5	36.1
97	19	0	-	0	30	0	90	0	12	0	2	6	17000	10	45	12	70	300	28.7	3.45	0	0	2.5	3.3	1.5	2.5	31.6
98	18	0	-	0	18	4.8	90	0	12	0	2	6	17000	10	5	1.5	70	150	14.4	1.72	0	0	2	2.1	1	0	22.0
99	8	5.6	-	0	12	7.2	90	0	10	2	2	6	17000	10	30	9	70	250	24	2.87	0	0	4	8.1	2.5	7.5	50.0
100	18	0	-	0	18	4.8	90	0	12	0	2	6	17000	10	5	1.5	70	400	38.3	4.6	0	0	3	4.6	1	0	26.4
101	11	3.2	-	0	11	7.6	90	0	11	1	2	6	17000	10	30	9	70	400	38.3	4.6	0	0	3	4.6	2.7	8.6	47.2

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 21a: Data and rating values for Highway 44.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
1	44	N37-32.591	W91-51.745	20	4.0	90	12	2	6	3	18	2	6	3	9	2	6	3	2	3	9	0	0	1	3	63.0
2	44	N37-32.582	W91-51.756	30	6.0	70	8	4	12	4	24	1.5	7.5	2	6	3	9	4	1	3	9	0	0	2	6	74.3
3	44	N37-33.222	W91-51.749	30	6.0	90	12	4	12	3.5	21	1	9	2	6	2.5	7.5	5	0	3	9	0	0	1	3	71.8
4	44	N37-33.234	W91-51.762	20	4.0	90	12	3	9	2	12	2	6	3	9	3	9	2.5	3	2	6	0	0	1	3	61.4
5	44	N37-34.068	W91-51.751	15	3.0	90	12	1	3	1	6	3	3	1	3	1.5	4.5	3.5	1	0	0	0	0	1	3	32.7
6	44	N37-34.083	W91-51.761	6	1.2	90	12	3	9	2	12	2	6	2	6	3	9	0.5	10	0	0	0	0	1	3	57.3
7	44	N37-34.083	W91-51.762	32	6.4	80	10	2.5	7.5	2.5	15	1.5	7.5	2	6	3	9	1.5	6	2	6	0	0	2	6	67.3
8	44	N37-35.368	W91-51.766	20	4.0	90	12	3	9	3	18	2	6	2	6	2.5	7.5	0.5	10	1	3	0	0	1	3	65.9
9	44	N37-35.748	W91-51.751	20	4.0	80	10	3	9	3	18	1.5	7.5	2	6	2.5	7.5	0.5	10	3	9	0	0	2	6	73.5
10	44	N37-35.749	W91-51.761	20	4.0	90	12	1	3	1.5	9	3	3	1.5	4.5	1.5	4.5	1	8	3	9	0	0	1	3	50.5
11	44	N37-36.167	W91-51.755	45	9.0	90	12	4	12	3.5	21	1.5	7.5	2	6	3	9	2.5	3	3	9	0	0	1	3	76.9
12	44	N37-36.187	W91-51.765	20	4.0	90	12	1	3	1	6	3	3	1	3	1.5	4.5	0.5	10	0	0	0	0	1	3	40.9
13	44	N37-36.740	W91-51.760	20	4.0	90	12	4	12	4	24	1	9	1.5	4.5	3	9	2	5	1	3	0	0	1	3	71.3
14	44	N37-36.747	W91-51.770	19	3.8	90	12	4	12	3	18	1.5	7.5	3	9	3	9	3	2	2	6	0	0	1	3	69.1
15	44	N37-47.359	W91-50.253	35	7.0	75	9	4	12	3.5	21	1.5	7.5	2.5	7.5	4	12	1	8	1	3	0	0	1	3	75.5
16	44	N37-47.363	W91-50.285	10	2.0	90	12	1.5	4.5	2.5	15	1.5	7.5	1.5	4.5	2	6	1	8	2.5	7.5	0	0	1	3	58.8
17	44	N37-47.475	W91-49.544	28	5.6	90	12	4	12	3.5	21	1.5	7.5	4	12	4	12	1.5	6	2	6	0	0	1	3	81.5
18	44	N37-47.615	W91-49.315	20	4.0	90	12	3	9	3	18	1	9	3	9	2	6	1.5	6	3	9	0	0	1	3	71.4
19	44	N37-47.640	W91-49.311	22	4.4	75	9	4	12	4	24	1	9	3	9	3	9	3	2	3	9	0	0	1	3	75.8
20	44	N37-49.965	W91-47.833	8	1.6	90	12	3	9	3	18	1.5	7.5	2	6	3	9	1.5	6	1	3	0	0	1	3	63.2
21	44	N37-49.973	W91-47.839	30	6.0	90	12	4	12	4	24	0.5	10.5	4	12	4	12	0.5	10	3	9	0	0	1	3	92.6
22	44	N37-54.134	W91-46.820	12	2.4	80	10	4	12	4	24	0.5	10.5	4	12	3	9	0.5	10	3	9	0	0	1	3	85.4
23	44	N37-54.137	W91-46.831	15	3.0	90	12	3	9	2.5	15	1	9	3	9	2	6	0.5	10	2.5	7.5	0	0	1	3	70.1

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 21a: Data and rating values for Highway 44 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
1	11	3.2	-	0	22	3.2	90	0	12	0	2	6	24000	12	30	9	70	600	81.2	9.74	1	4	3	4.6	1.4	1.8	45.0
2	12	7.2	2	8	24	2.4	70	2	12	0	2	6	24000	12	90	12	70	600	81.2	9.74	2	8	4	8.1	3.8	14	70.9
3	14	0.8	-	0	42	0	90	0	12	0	2	6	24000	12	80	12	70	270	36.5	4.38	1	4	5	12.0	1.9	4.5	47.2
4	10	4	-	0	20	4	90	0	12	0	2	6	24000	12	15	4.5	70	160	21.6	2.6	1	4	2.5	3.3	1	0	33.6
5	16	0	-	0	24	2.4	90	0	10	2	2	6	24000	12	5	1.5	70	320	43.3	5.19	0.5	2	3.5	6.3	1	0	31.1
6	6	7.2	-	0	12	7.2	90	0	12	0	3	3	24000	12	5	1.5	70	170	15.3	1.84	0	0	0.5	0.3	1	0	27.5
7	10	8	3	12	10	8	80	9	11	1	1	12	5000	3	16	4.8	55	470	33.7	4.05	0.5	2	1.5	1.3	1.6	3	52.3
8	9	4.8	-	0	15	6	90	0	11	1	2	6	24000	12	15	4.5	70	560	75.8	9.09	0.5	2	0.5	0.3	1	0	38.0
9	8	8.8	2	8	8	8.8	80	9	10	2	2	6	24000	12	30	9	70	600	81.2	9.74	1	4	0.5	0.3	3.8	14	72.5
10	22	0	-	0	44	0	90	0	11	1	2	6	24000	12	10	3	70	500	67.6	8.12	0	0	1	0.6	1	0	25.6
11	20	4	2	8	40	0	90	0	9	3	2	6	24000	12	30	9	70	720	97.4	11.7	0	0	2.5	3.3	1	0	43.1
12	20	0	-	0	40	0	90	0	11	1	2	6	24000	12	10	3	70	450	60.9	7.31	0	0	0.5	0.3	1	0	24.6
13	19	0	-	0	40	0	90	0	7	5	3	3	24000	12	30	9	70	870	78.5	9.42	1	4	2	2.1	1	0	37.1
14	17	0	-	0	36	0	90	0	8	4	2	6	24000	12	30	9	70	270	36.5	4.38	0	0	3	4.6	1	0	33.3
15	7	9.2	2	8	14	6.4	75	4.5	10	2	2	6	24000	12	35	10.5	70	400	54.1	6.49	1	4	1	0.6	2.5	7.5	60.3
16	6	7.2	-	0	12	7.2	90	0	11	1	2	6	24000	12	10	3	70	440	59.5	7.14	0	0	1	0.6	1	0	36.8
17	6	7.2	-	0	12	7.2	90	0	9	3	2	6	24000	12	20	6	70	750	101	12	1	4	1.5	1.3	1.7	3.3	52.2
18	5	8	-	0	5	10	90	0	10	2	2	6	24000	12	20	6	70	830	112	12	0	0	1.5	1.3	4	15	62.7
19	6	9.6	2	8	12	7.2	75	4.5	9	3	2	6	24000	12	75	12	70	750	101	12	2	8	3	4.6	6.3	15	80.9
20	7	6.4	-	0	14	6.4	90	0	10	2	2	6	24000	12	10	3	70	150	20.3	2.44	0	0	1.5	1.3	1	0	32.9
21	7	6.4	-	0	7	9.2	90	0	10	2	2	6	24000	12	30	9	70	900	122	12	1	4	0.5	0.3	4.3	15	65.7
22	8	8.8	2	8	12	7.2	80	9	10	2	2	6	24000	12	30	9	70	700	94.7	11.4	0	0	0.5	0.3	2.5	7.5	63.3
23	5	8	-	0	8	8.8	90	0	10	2	2	6	24000	12	20	6	70	350	47.3	5.68	0	0	0.5	0.3	2.5	7.5	48.1

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 21b: Data and rating values for Highway 44.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Ris
24	44	N37-54.219	W91-46.674	22	4.4	80	10	4	12	3.5	21	1	9	2	6	3	9	3	2	3	9	0	0	1	3	71.7
25	44	N37-54.222	W91-46.681	30	6.0	90	12	1.5	4.5	2.5	15	2.5	4.5	1	3	1.5	4.5	3	2	3	9	0	0	1	3	53.4
26	44	N38-02.412	W91-46.601	27	5.4	90	12	1	3	1.5	9	3.5	1.5	1	3	1	3	4	1	3	9	0	0	1	3	41.7
27	44	N38-02.412	W91-46.549	20	4.0	90	12	1	3	1	6	3.5	1.5	1	3	1.5	4.5	4	1	3	9	0	0	1	3	39.2
28	44	N38-02.459	W91-46.608	10	2.0	90	12	1	3	1.5	9	2	6	1	3	1	3	1	8	1	3	0	0	1	3	43.8
29	44	N38-01.459	W91-46.599	15	3.0	90	12	2	6	1.5	9	1.5	7.5	1	3	2	6	2	5	2	6	0	0	1	3	50.5
30	44	N38-00.897	W91-46.547	20	4.0	90	12	3	9	3	18	1.5	7.5	3	9	3	9	2	5	3	9	0	0	1	3	71.3
31	44	N38-00.902	W91-46.539	25	5.0	75	9	4	12	4	24	0.5	10.5	3	9	4	12	3.5	1	3	9	0	0	1	3	79.3
32	44	N38-00.860	W91-46.531	35	7.0	90	12	3	9	2.5	15	2.5	4.5	1	3	2	6	3	2	0	0	0	0	1	3	51.7
33	44	N38-00.787	W91-46.533	17	3.4	90	12	4	12	3	18	1	9	2.5	7.5	3	9	1	8	1	3	0	0	1	3	71.2
34	44	N38-00.751	W91-46.517	30	6.0	90	12	4	12	4	24	0.5	10.5	3.5	10.5	3	9	1.5	6	1	3	0	0	1	3	80.6
35	44	N38-00.499	W91-46.502	18	3.6	90	12	4	12	3.5	21	0.5	10.5	3	9	3	9	0.5	10	2	6	0	0	1	3	80.6
36	44	N38-00.504	W91-46.494	12	2.4	70	8	4	12	3	18	1	9	3	9	3	9	2	5	1	3	0	0	1	3	65.4
37	44	N37-58.520	W91-45.620	14	2.8	90	12	3	9	3	18	1	9	3	9	3	9	0.5	10	2	6	0	0	1	3	73.6
38	44	N37-58.486	W91-45.601	20	4.0	90	12	4	12	4	24	1	9	4	12	4	12	0.5	10	1	3	0	0	1	3	84.6
39	44	N38-07.733	W91-48.296	23	4.6	90	12	3.5	10.5	3	18	1	9	2	6	3.5	10.5	2	5	0	0	0	0	1	3	65.6
40	44	N38-07.701	W91-48.216	35	7.0	90	12	3	9	3	18	1	9	2	6	3	9	1.5	6	2	6	0	0	1	3	71.4
41	44	N38-07.717	W91-48.279	35	7.0	90	12	1	3	1	6	3	3	1	3	0	0	4	1	2	6	0	0	1	3	36.8
42	44	N38-07.752	W91-48.388	30	6.0	90	12	3.5	10.5	3.5	21	1	9	3	9	3	9	4	1	2	6	0	0	1	3	72.2
43	44	N38-07.795	W91-48.559	19	3.8	90	12	1	3	2	12	2.5	4.5	1	3	2	6	1	8	2	6	0	0	1	3	51.6
44	44	N38-07.764	W91-48.480	18	3.6	60	6	3	9	3	18	1	9	3	9	4	12	2	5	1	3	0	0	1	3	64.7
45	44	N38-07.858	W91-48.830	25	5.0	75	9	2	6	2.5	15	3	3	1	3	2.5	7.5	1.5	6	1	3	0	0	1	3	51.0
46	44	N38-07.837	W91-48.796	22	4.4	75	9	2	6	1.5	9	2	6	2	6	3	9	2	5	0	0	0	0	1	3	47.9

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 21b: Data and rating values for Highway 44 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
24	7	9.2	2	8	10	8	80	9	10	2	2	6	24000	12	20	6	70	700	94.7	11.4	0	0	3	4.6	2	5	62.7
25	15	0	-	0	30	0	90	0	6	6	2	6	24000	12	15	4.5	70	770	104	12	0	0	3	4.6	1	0	37.6
26	20	0	-	0	32	0	90	0	7	5	3	3	24000	12	5	1.5	70	650	58.6	7.03	0	0	4	8.1	1	0	30.5
27	18	0	-	0	33	0	90	0	11	1	2	6	24000	12	5	1.5	70	500	67.6	8.12	0	0	4	8.1	1	0	30.6
28	18	0	-	0	24	2.4	90	0	10	2	2	6	24000	12	5	1.5	70	300	40.6	4.87	0	0	1	0.6	1	0	24.5
29	19	0	-	0	29	0.4	90	0	0	12	2	6	24000	12	15	4.5	70	600	81.2	9.74	0	0	2	2.1	1	0	39.0
30	6	7.2	-	0	12	7.2	90	0	10	2	2	6	24000	12	20	6	70	144	19.5	2.34	2	8	2	2.1	1.7	3.3	47.4
31	6	9.6	2	8	16	5.6	75	4.5	10	2	2	6	24000	12	30	9	70	850	115	12	0	0	3.5	6.3	1.9	4.4	61.2
32	16	5.6	1.5	6	32	0	90	0	10	2	2	6	24000	12	60	12	70	420	56.8	6.82	0	0	3	4.6	1.9	4.4	46.1
33	21	0	-	0	42	0	90	0	10	2	2	6	24000	12	34	10.2	70	250	33.8	4.06	0	0	1	0.6	1	0	29.1
34	6	7.2	-	0	18	4.8	90	0	10	2	2	6	24000	12	45	12	70	500	67.6	8.12	0	0	1.5	1.3	2.5	7.5	52.0
35	6	7.2	-	0	17	5.2	90	0	10	2	2	6	24000	12	36	10.8	70	400	54.1	6.49	2	8	0.5	0.3	2.1	5.6	53.9
36	6	9.6	1.5	6	17	5.2	70	2	9	3	2	6	24000	12	10	3	70	300	40.6	4.87	2	8	2	2.1	1	0	46.8
37	4	8.8	-	0	10	8	90	0	11	1	2	6	24000	12	28	8.4	70	480	64.9	7.79	2	8	0.5	0.3	2.8	9	59.2
38	24	0	-	0	36	0	90	0	11	1	2	6	24000	12	60	12	70	600	81.2	9.74	0	0	0.5	0.3	1.7	3.3	37.5
39	23	0	-	0	46	0	90	0	11	1	2	6	24000	12	40	12	70	175	23.7	2.84	0	0	2	2.1	1	0	30.0
40	23	0	-	0	46	0	90	0	11	1	2	6	24000	12	40	12	70	300	40.6	4.87	0	0	1.5	1.3	1	0	30.9
41	23	0	-	0	36	0	90	0	8	4	3	3	24000	12	5	1.5	70	600	54.1	6.49	0	0	4	8.1	1	0	29.2
42	23	0	-	0	36	0	90	0	8	4	3	3	24000	12	60	12	70	400	36.1	4.33	0	0	4	8.1	1.7	3.3	39.5
43	18	0	-	0	24	2.4	90	0	7	5	3	3	24000	12	15	4.5	70	350	31.6	3.79	0	0	1	0.6	1	0	26.1
44	17	5.2	1.5	6	34	0	60	4	3	9	2	6	24000	12	30	9	70	400	54.1	6.49	1	4	2	2.1	1	0	48.4
45	21	3.6	1.5	6	42	0	75	4.5	11	1	1	12	24000	12	5	1.5	70	200	54.1	6.49	2	8	1.5	1.3	1	0	42.7
46	16	5.6	1.5	6	32	0	75	4.5	3	9	1	12	24000	12	15	4.5	70	200	54.1	6.49	1.5	6	2	2.1	1	0	51.7

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 21c: Data and rating values for Highway 44..

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
47	44	N38-07.990	W91-49.489	9	1.8	90	12	1.5	4.5	1	6	3	3	3	9	2	6	1.5	6	0	0	1	4	1	3	47.3
48	44	N38-07.979	W91-49.538	12	2.4	90	12	3	9	3	18	1	9	4	12	3	9	3	2	2	6	0	0	2	6	72.1
49	44	N38-07.646	W91-51.163	13	2.6	80	10	4	12	4	24	0.5	10.5	4	12	4	12	1.5	6	1	3	0	0	1	3	79.8
50	44	N38-07.646	W91-51.163	10	2.0	90	12	4	12	4	24	0.5	10.5	3.5	10.5	3.5	10.5	1.5	6	1	3	0	0	1	3	78.5
51	44	N38-07.705	W91-51.314	10	2.0	90	12	4	12	4	24	0.5	10.5	3	9	4	12	0.5	10	1	3	0	0	1	3	81.7
52	44	N38-07.705	W91-51.314	17	3.4	90	12	4	12	4	24	0.5	10.5	4	12	4	12	1	8	1	3	0	0	1	3	83.7
53	44	N38-07.843	W91-51.563	12	2.4	90	12	3	9	3.5	21	1	9	2	6	3	9	1	8	0	0	0	0	1	3	66.6
54	44	N38-07.843	W91-51.563	25	5.0	90	12	4	12	4	24	0.5	10.5	4	12	4	12	4	1	2	6	0	0	3	9	87.3
55	44	N38-08.835	W91-53.069	25	5.0	90	12	3.5	10.5	4	24	1	9	3	9	4	12	1	8	1	3	0	0	2	6	83.1
56	44	N38-08.835	W91-53.069	12	2.4	65	7	0.5	1.5	0.5	3	3	3	2.5	7.5	2	6	1	8	1	3	0	0	1	3	37.5
57	44	N38-08.974	W91-53.517	15	3.0	50	4	3	9	3	18	0.5	10.5	2	6	3	9	5	0	2	6	0	0	1	3	57.6
58	44	N38-08.974	W91-53.517	20	4.0	85	11	4	12	3	18	0.5	10.5	3.5	10.5	4	12	2	5	1	3	2	8	3	9	88.2
59	44	N38-21.254	W91-55.273	13	2.6	90	12	2	6	1.5	9	2.5	4.5	3.5	10.5	1.5	4.5	1	8	1	3	0	0	1	3	53.1
60	44	N38-21.254	W91-55.273	20	4.0	90	12	3.5	10.5	3	18	1.5	7.5	4	12	3	9	2.5	3	1	3	1	4	1	3	72.9
61	44	N38-21.891	W91-55.657	8	1.6	90	12	3.5	10.5	3	18	2	6	3.5	10.5	4	12	0.2	11	0	0	0	0	1	3	71.1
62	44	N38-23.270	W91-55.860	12	2.4	80	10	2.5	7.5	2.5	15	2	6	3	9	3.5	10.5	0.2	11	0	0	0	0	1	3	62.7
63	44	N38-23.270	W91-55.860	15	3.0	90	12	4	12	2	12	1.5	7.5	3	9	4	12	4	1	0	0	0	0	1	3	59.7
64	44	N38-23.413	W91-55.992	14	2.8	90	12	3	9	1.5	9	2	6	2	6	3	9	2	5	0	0	0	0	1	3	51.6
65	44	N38-23.413	W91-55.992	20	4.0	90	12	3.5	10.5	1	6	2	6	3	9	3	9	1	8	0	0	0	0	1	3	56.7
66	44	N38-25.410	W91-58.890	40	8.0	90	12	4	12	3	18	1.5	7.5	3	9	4	12	3	2	2	6	0	0	1	3	75.1
67	44	N38-25.484	W91-58.980	20	4.0	90	12	2.5	7.5	1.5	9	1.5	7.5	4	12	3.5	10.5	0.5	10	0	0	0	0	1	3	63.4
68	44	N38-25.544	W91-59.017	25	5.0	90	12	3.5	10.5	3	18	0.5	10.5	4	12	4	12	4	1	2	6	0	0	1	3	75.1
69	44	N38-25.410	W91-58.890	45	9.0	85	11	4	12	4	24	1	9	3.5	10.5	3.5	10.5	2	5	0	0	0	0	1	3	78.4

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 21c: Data and rating values for Highway 44 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
47	10	4	-	0	15	6	90	0	12	0	2	6	24000	12	10	3	70	450	60.9	7.31	1	4	1.5	1.3	1	0	36.3
48	9	4.8	-	0	9	8.4	90	0	12	0	2	6	24000	12	36	10.8	70	300	40.6	4.87	1	4	3	4.6	4	15	61.3
49	10	8	2	8	15	6	80	9	12	0	2	6	24000	12	52	12	70	120	16.2	1.95	1.5	6	1.5	1.3	3.5	12	65.5
50	7	6.4	-	0	3.5	11	90	0	11	1	2	6	24000	12	25	7.5	70	150	20.3	2.44	0	0	1.5	1.3	7.1	15	54.3
51	7	6.4	-	0	3.5	11	90	0	11	1	2	6	24000	12	25	7.5	70	100	13.5	1.62	0	0	0.5	0.3	7.1	15	52.8
52	7	6.4	-	0	7	9.2	90	0	8	4	1	12	5000	3	60	12	55	300	21.5	2.58	0	0	1	0.6	8.6	15	56.5
53	11	3.2	-	0	11	7.6	90	0	1	11	1	12	5000	3	25	7.5	55	300	21.5	2.58	0	0	1	0.6	2.3	6.4	46.0
54	20	0	-	0	30	0	90	0	4.5	7.5	2	6	24000	12	120	12	70	150	20.3	2.44	2	8	4	8.1	4	15	61.7
55	16	0	-	0	24	2.4	90	0	8	4	2	6	24000	12	120	12	70	150	20.3	2.44	1.5	6	1	0.6	5	15	52.9
56	6	9.6	2	8	12	7.2	65	3	11	1	2	6	24000	12	5	1.5	70	550	74.4	8.93	0.5	2	1	0.6	1	0	45.4
57	10	8	2	8	20	4	50	7	11	1	2	6	24000	12	40	12	70	270	36.5	4.38	3	12	5	12.0	2	5	70.4
58	8	8.8	2	8	8	8.8	85	12	11	1	2	6	24000	12	100	12	70	300	40.6	4.87	0.5	2	2	2.1	13	15	73.8
59	16	0	-	0	32	0	90	0	11	1	2	6	24000	12	10	3	70	190	25.7	3.08	0	0	1	0.6	1	0	21.4
60	9	4.8	-	0	14	6.4	90	0	10	2	2	6	24000	12	40	12	70	350	47.3	5.68	1	4	2.5	3.3	2.9	9.3	56.1
61	9	4.8	-	0	9	8.4	90	0	9	3	2	6	24000	12	15	4.5	70	600	81.2	9.74	0.5	2	0.2	0.2	1.7	3.3	45.5
62	8	8.8	2	8	8	8.8	80	9	8	4	2	6	24000	12	20	6	70	300	40.6	4.87	1	4	0.2	0.2	2.5	7.5	61.8
63	6	7.2	-	0	6	9.6	90	0	9	3	2	6	24000	12	40	12	70	550	74.4	8.93	1	4	4	8.1	6.7	15	74.0
64	6	7.2	-	0	6	9.6	90	0	9	3	2	6	24000	12	20	6	70	300	40.6	4.87	0.5	2	2	2.1	3.3	12	55.7
65	8	5.6	-	0	16	5.6	90	0	9	3	2	6	24000	12	40	12	70	600	81.2	9.74	0.5	2	1	0.6	2.5	7.5	54.7
66	12	2.4	-	0	18	4.8	90	0	9	3	2	6	24000	12	60	12	70	800	108	12	0.5	2	3	4.6	3.3	12	60.7
67	6	7.2	-	0	9	8.4	90	0	9	3	2	6	24000	12	30	9	70	350	47.3	5.68	0.5	2	0.5	0.3	3.3	12	56.3
68	5	8	-	0	10	8	90	0	10	2	2	6	24000	12	20	6	70	650	87.9	10.6	0.5	2	4	8.1	2	5	57.2
69	22	3.2	2	8	33	0	85	12	12	0	2	6	24000	12	150	12	70	400	54.1	6.49	2	8	2	2.1	4.5	15	67.9

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 21d: Data and rating values for Highway 44.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Ris
70	44	N38-25.484	W91-58.980	45	9.0	85	11	4	12	4	24	0.5	10.5	4	12	4	12	2.5	3	0	0	0	0	2	6	84.0

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 21d: Data and rating values for Highway 44 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
70	20	4	2	8	20	4	85	12	12	0	2	6	24000	12	150	12	70	400	54.1	6.49	1	4	2.5	3.3	7.5	15	69.4

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 22a: Data and rating values for Highway 65.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
1	65	N 37-06.886	W 93-14.056	30	6.0	90	12	1	3	0.5	3	3.5	1.5	2	6	2	6	4	1	3	9	0	0	1	3	42.2
2	65	N 37-06.465	W 93-14.001	8	1.6	90	12	1.5	4.5	1	6	2	6	1.5	4.5	2.5	7.5	2	5	1	3	0	0	1	3	44.3
3	65	N 37-05.414	W 93-13.869	12	2.4	90	12	0.5	1.5	0.5	3	3	3	0	0	1.5	4.5	5	0	1	3	0	0	1	3	27.5
4	65	N 37-00.752	W 93-13.773	12	2.4	90	12	1	3	1.5	9	0	12	0.5	1.5	1	3	4	1	1	3	0	0	1	3	41.7
5	65	N 37-00.493	W 93-13.786	8	1.6	90	12	0	0	0.5	3	3	3	0	0	0.5	1.5	4.5	0	1	3	0	0	1	3	23.2
6	65	N 37-00.493	W 93-13.786	20	4.0	90	12	3	9	3.5	21	1	9	3.5	10.5	3	9	4	1	1	3	0	0	3	9	74.0
7	65	N 36-54.143	W 93-14.494	35	7.0	90	12	4	12	4	24	0.5	10.5	4	12	3	9	2.5	3	1	3	0	0	1	3	80.2
8	65	N 36-52.086	W 93-13.772	25	5.0	90	12	4	12	3.5	21	1.5	7.5	3	9	3	9	5	0	2	6	0	0	3	9	76.9
9	65	N 36-51.722	W 93-13.666	50	10.0	90	12	4	12	3.5	21	3.5	1.5	3.5	10.5	3.5	10.5	2	5	1	3	0	0	1	3	73.8
10	65	N 36-51.518	W 93-13.596	30	6.0	90	12	2	6	3	18	1.5	7.5	2	6	2	6	4	1	1	3	0	0	1	3	57.2
11	65	N 36-51.021	W 93-13.354	30	6.0	90	12	3.5	10.5	4	24	1.5	7.5	4	12	3.5	10.5	2	5	0	0	0	0	1	3	75.5
12	65	N 36-49.937	W 93-13.176	22	4.4	90	12	4	12	3	18	1	9	3	9	2.5	7.5	2.5	3	1	3	0	0	1	3	68.0
13	65	N 36-49.758	W 93-13.206	50	10.0	90	12	0.5	1.5	1	6	3	3	0.5	1.5	1	3	4	1	1	3	0	0	1	3	36.8
14	65	N 36-49.490	W 93-13.462	22	4.4	90	12	3.5	10.5	3.5	21	1	9	3.5	10.5	3.5	10.5	2	5	0	0	0	0	1	3	71.7
15	65	N 36-49.490	W 93-13.462	22	4.4	90	12	0.5	1.5	0.5	3	3	3	0.5	1.5	1	3	2	5	0	0	0	0	1	3	30.4
16	65	N 36-49.051	W 93-13.574	25	5.0	90	12	4	12	4	24	1	9	2.5	7.5	3	9	3	2	0	0	0	0	1	3	70.1
17	65	N 36-46.923	W 93-13.490	30	6.0	90	12	4	12	4	24	1	9	2.5	7.5	4	12	5	0	3	9	0	0	3	9	85.3
18	65	N 36-46.753	W 93-13.487	28	5.6	90	12	1.5	4.5	2.5	15	2	6	1.5	4.5	2.5	7.5	4	1	1	3	0	0	1	3	51.8
19	65	N 36-46.753	W 93-13.472	28	5.6	90	12	4	12	4	24	0.5	10.5	2	6	4	12	4	1	2	6	0	0	2	6	79.8
20	65	N 36-46.753	W 93-13.472	28	5.6	90	12	0	0	1	6	3	3	1.5	4.5	0.5	1.5	4	1	2	6	0	0	1	3	35.6
21	65	N 36-45.725	W 93-13.383	65	12.0	90	12	1	3	1	6	3	3	1	3	1.5	4.5	2.5	3	1	3	0	0	1	3	44.4
22	65	N 36-44.524	W 93-13.337	28	5.6	90	12	0	0	0.5	3	3.5	1.5	0	0	0.5	1.5	3	2	2	6	0	0	1	3	29.3
23	65	N 36-44.539	W 93-13.312	28	5.6	90	12	1.5	4.5	1.5	9	2	6	0.5	1.5	1	3	2	5	1.5	4.5	0	0	1	3	45.2

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularit ies, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 22a: Data and Rating values for Highway 65 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
1	11	3.2	-	0	11	7.6	90	0	12	0	2	6	24000	12	10	3	65	200	29.1	3.5	1	4	4	8.1	1	0	39.5
2	13	1.6	-	0	13	6.8	90	0	12	0	2	6	24000	12	8	2.4	65	200	29.1	3.5	0.5	2	2	2.1	1	0	30.4
3	20	0	-	0	20	4	90	0	11	1	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	5	12.0	1	0	30.8
4	23	0	-	0	34	0	90	0	11	1	2	6	24000	12	5	1.5	65	100	14.6	1.75	0	0	4	8.1	1	0	25.3
5	22	0	-	0	33	0	90	0	10.5	1.5	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	4.5	10.1	1	0	26.2
6	22	0	-	0	33	0	90	0	6	6	2	6	24000	12	60	12	65	500	72.8	8.74	0	0	4	8.1	1.8	4.1	48.1
7	10	4	-	0	15	6	90	0	10	2	2	6	24000	12	60	12	65	300	43.7	5.24	0	0	2.5	3.3	4	15	57.1
8	7	6.4	-	0	7	9.2	90	0	10	2	2	6	24000	12	40	12	65	500	72.8	8.74	0	0	5	12.0	5.7	15	71.9
9	8	8.8	2	8	8	8.8	90	0	11	1	2	6	24000	12	40	12	65	500	72.8	8.74	0	0	2	2.1	5	15	66.1
10	8	8.8	2	8	8	8.8	90	0	11	1	2	6	24000	12	30	9	65	100	14.6	1.75	0	0	4	8.1	3.8	14	61.8
11	10	8	2	8	10	8	90	0	10.5	1.5	2	6	24000	12	40	12	65	450	65.6	7.87	0	0	2	2.1	4	15	64.6
12	10	8	2	8	10	8	90	0	10	2	2	6	24000	12	40	12	65	470	68.5	8.22	0	0	2.5	3.3	4	15	66.1
13	24	0	-	0	36	0	90	0	11	1	2	6	24000	12	5	1.5	65	25	3.64	0.44	1	4	4	8.1	1	0	27.5
14	12	2.4	-	0	6	9.6	90	0	10	2	2	6	24000	12	30	9	65	200	29.1	3.5	0	0	2	2.1	5	15	53.9
15	12	2.4	-	0	6	9.6	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	2	2.1	1	0	30.1
16	9	8.4	2	8	9	8.4	90	0	9	3	2	6	24000	12	40	12	65	400	58.3	6.99	1	4	3	4.6	4.4	15	70.6
17	24	0	-	0	48	0	90	0	11	1	2	6	24000	12	120	12	65	350	51	6.12	0	0	5	12.0	2.5	7.5	48.4
18	24	0	-	0	36	0	90	0	10	2	2	6	24000	12	20	6	65	100	14.6	1.75	0	0	4	8.1	1	0	29.9
19	22	0	-	0	44	0	90	0	11	1	2	6	24000	12	100	12	65	100	14.6	1.75	0	0	4	8.1	2.3	6.4	40.4
20	22	0	-	0	44	0	90	0	11	1	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	4	8.1	1	0	24.2
21	28	0	-	0	56	0	90	0	10	2	2	6	24000	12	5	1.5	65	200	29.1	3.5	1	4	2.5	3.3	1	0	26.9
22	30	0	-	0	60	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	3	4.6	1	0	22.1
23	30	0	-	0	60	0	90	0	10	2	2	6	24000	12	15	4.5	65	25	3.64	0.44	0	0	2	2.1	1	0	22.6

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 22b: Data and rating values for Highway 65.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
24	65	N 36-44.172	W 93-13.284	30	6.0	90	12	0	0	0.5	3	3.5	1.5	0	0	0.5	1.5	5	0	1	3	0	0	1	3	25.5
25	65	N 36-44.201	W 93-13.257	55	11.0	90	12	0	0	0	0	3	3	0	0	1	3	5	0	2	6	0	0	1	3	32.2
26	65	N 36-43.787	W 93-13.249	40	8.0	90	12	0	0	0	0	3.5	1.5	0	0	0	0	5	0	0	0	0	0	1	3	20.9
27	65	N 36-43.787	W 93-13.249	40	8.0	90	12	4	12	4	24	0.5	10.5	3	9	4	12	5	0	2	6	0	0	2	6	83.9
28	65	N 36-43.147	W 93-13.260	45	9.0	90	12	0.5	1.5	0	0	3.5	1.5	0	0	1	3	3	2	2	6	0	0	3	9	38.2
29	65	N 36-42.721	W 93-13.261	25	5.0	90	12	0	0	0	0	3	3	0	0	0.5	1.5	4	1	0	0	0	0	1	3	21.3
30	65	N 36-42.729	W 93-13.315	80	12.0	90	12	0.5	1.5	0	0	3	3	2	6	1.5	4.5	3	2	0.5	1.5	0	0	1	3	38.4
31	65	N 36-42.728	W 93-13.316	55	11.0	90	12	0	0	0	0	3	3	0.5	1.5	1.5	4.5	3	2	1.5	4.5	0	0	1	3	35.1
32	65	N 36-42.567	W 93-13.293	45	9.0	90	12	0	0	0	0	25	-63	0	0	0.5	1.5	2.5	3	1	3	0	0	1	3	30.6
33	65	N 36-41.841	W 93-13.270	22	4.4	90	12	0	0	0	0	3	3	0	0	0.5	1.5	2	5	1	3	0	0	1	3	26.7
34	65	N 36-41.841	W 93-13.270	22	4.4	90	12	3.5	10.5	3.5	21	0.5	10.5	2	6	3	9	3	2	2	6	0	0	2	6	73.8
35	65	N 36-41.169	W 93-13.279	30	6.0	90	12	1	3	1.5	9	3	3	1.5	4.5	1	3	3.5	1	1.5	4.5	0	0	1	3	41.4
36	65	N 36-39.796	W 93-13.339	20	4.0	90	12	1.5	4.5	2	12	2.5	4.5	1.5	4.5	2	6	3	2	0.5	1.5	0	0	1	3	45.5
37	65	N 36-39.614	W 93-13.353	33	6.6	90	12	1.5	4.5	2	12	2	6	1	3	1	3	2	5	1	3	0	0	1	3	48.5
38	65	N 36-39.279	W 93-13.343	55	11.0	90	12	2.5	7.5	2	12	2.5	4.5	0.5	1.5	2	6	3.5	1	0	0	0	0	1	3	49.4
39	65	N 36-39.197	W 93-13.350	25	5.0	90	12	3	9	2.5	15	1.5	7.5	1.5	4.5	2	6	3	2	1	3	0	0	1	3	56.3
40	65	N 36-38.690	W 93-13.660	20	4.0	90	12	0.5	1.5	1.5	9	2.5	4.5	1	3	0.5	1.5	2	5	0	0	0	0	1	3	36.3
41	65	N 36-38.683	W 93-13.628	25	5.0	90	12	1	3	2.5	15	2	6	1	3	1.5	4.5	3	2	1	3	0	0	1	3	47.6
42	65	N 36-40.376	W 93-13.256	35	7.0	90	12	0.5	1.5	0.5	3	3.5	1.5	1	3	2	6	5	0	1	3	0	0	1	3	33.9
43	65	N 36-40.273	W 93-13.252	25	5.0	90	12	0	0	0	0	3	3	0.5	1.5	0.5	1.5	3	2	3	9	0	0	1	3	31.3
44	65	N 36-40.702	W 93-13.263	30	6.0	90	12	0	0	1	6	3	3	1	3	1	3	3	2	1	3	0	0	1	3	34.7
45	65	N 36-40.702	W 93-13.263	30	6.0	90	12	3	9	4	24	0.5	10.5	2.5	7.5	2	6	3	2	1	3	0	0	1	3	69.7
46	65	N 36-41.175	W 93-13.257	35	7.0	90	12	1	3	1	6	2	6	2	6	2	6	2	5	3	9	0	0	1	3	52.6

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 22b: Data and rating values for Highway 65 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
24	31	0	-	0	62	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	5	12.0	1	0	28.3
25	30	0	-	0	60	0	90	0	10	2	2	6	24000	12	20	6	65	100	14.6	1.75	0	0	5	12.0	1	0	33.1
26	31	0	-	0	62	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	5	12.0	1	0	28.3
27	31	0	-	0	62	0	90	0	10	2	2	6	24000	12	150	12	65	100	14.6	1.75	0	0	5	12.0	2.4	7.1	45.2
28	30	0	-	0	60	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	3	4.6	1	0	22.1
29	32	0	-	0	48	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	4	8.1	1	0	25.0
30	30	0	-	0	45	0	90	0	5	7	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	3	4.6	1	0	26.3
31	32	0	-	0	48	0	90	0	5	7	2	6	24000	12	5	1.5	65	25	3.64	0.44	0.5	2	3	4.6	1	0	28.0
32	31	0	-	0	46	0	90	0	8	4	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	2.5	3.3	1	0	22.7
33	30	0	-	0	60	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0.5	2	2	2.1	1	0	21.7
34	30	0	-	0	60	0	90	0	10	2	2	6	24000	12	60	12	65	100	14.6	1.75	0.5	2	3	4.6	1	0	33.6
35	26	0	-	0	52	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	3.5	6.3	1	0	23.5
36	15	0	-	0	15	6	90	0	12	0	2	6	24000	12	20	6	65	50	7.28	0.87	0	0	3	4.6	1.3	1.7	31.3
37	20	0	-	0	30	0	90	0	8	4	2	6	24000	12	10	3	65	25	3.64	0.44	0	0	2	2.1	1	0	23.0
38	12	7.2	1.5	6	18	4.8	90	0	15	0	2	6	24000	12	20	6	65	200	29.1	3.5	0	0	3.5	6.3	1.1	0.6	39.8
39	15	6	1.5	6	22	3.2	90	0	13	0	2	6	24000	12	50	12	65	300	43.7	5.24	1	4	3	4.6	2.3	6.4	51.1
40	18	0	-	0	18	4.8	90	0	8	4	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	2	2.1	1	0	25.7
41	21	0	-	0	31	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	3	4.6	1	0	22.1
42	15	6	1.5	6	20	4	90	0	15	0	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	5	12.0	1	0	36.3
43	18	0	-	0	36	0	90	0	16	0	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	3	4.6	1	0	20.5
44	23	0	-	0	46	0	90	0	15	0	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	3	4.6	1	0	20.5
45	23	0	-	0	46	0	90	0	15	0	2	6	24000	12	40	12	65	50	7.28	0.87	0	0	3	4.6	1	0	29.6
46	27	0	-	0	54	0	90	0	11	1	2	6	24000	12	10	3	65	200	29.1	3.5	0	0	2	2.1	1	0	23.0

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 22c: Data and rating values for Highway 65.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
47	65	N 36-42.680	W 93-13.266	40	8.0	90	12	0	0	0	0	3.5	1.5	0.5	1.5	1	3	3	2	2	6	0	0	1	3	31.3
48	65	N 36-42.655	W 93-13.397	45	9.0	90	12	0.5	1.5	0	0	3	3	0	0	0.5	1.5	4	1	2	6	0	0	1	3	30.9
49	65	N 36-42.696	W 93-13.846	40	8.0	90	12	0	0	0	0	2.5	4.5	0.5	1.5	0.5	1.5	2	5	1	3	0	0	1	3	32.2
50	65	N 36-42.658	W 93-13.793	85	12.0	90	12	4	12	4	24	0.5	10.5	2	6	3	9	3	2	2	6	0	0	2	6	83.9
51	65	N 36-42.658	W 93-13.793	85	12.0	90	12	1.5	4.5	1	6	2.5	4.5	0	0	1	3	3	2	2	6	0	0	1	3	44.7
52	65	N 36-43.776	W 93-13.231	55	11.0	90	12	0	0	0	0	3.5	1.5	0	0	0.5	1.5	4	1	0	0	0	0	1	3	25.1
53	65	N 36-43.776	W 93-13.231	55	11.0	90	12	3.5	10.5	3.5	21	1	9	0	0	4	12	4	1	0	0	0	0	1	3	66.4
54	65	N 36-44.862	W 93-13.326	100	12.0	90	12	0	0	0	0	3.5	1.5	0	0	0.5	1.5	4	1	0.5	1.5	0	0	1	3	27.2
55	65	N 36-44.462	W 93-13.326	100	12.0	90	12	3	9	2	12	2	6	1	3	3	9	4	1	1	3	0	0	2	6	61.4
56	65	N 36-45.796	W 93-13.359	100	12.0	90	12	4	12	4	24	0.5	10.5	3	9	3	9	5	0	1	3	0	0	1.5	4.5	80.8
57	65	N 36-45.796	W 93-13.359	100	12.0	90	12	0.5	1.5	0.5	3	3.5	1.5	1	3	1.5	4.5	5	0	1	3	0	0	1	3	36.8
58	65	N 36-49.458	W 93-13.465	55	11.0	90	12	1.5	4.5	0.5	3	3	3	1	3	2	6	3	2	0	0	0	0	1	3	40.1
59	65	N 36-49.542	W 93-13.374	45	9.0	90	12	0.5	1.5	1	6	3	3	1	3	1	3	4	1	3	9	0	0	1	3	42.2
60	65	N 36-50.008	W 93-13.140	110	12.0	90	12	0.5	1.5	0	0	3	3	0.5	1.5	0.5	1.5	5	0	1	3	0	0	1	3	31.8

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 22c: Data and Rating values for Highway 65 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
47	26	0	-	0	39	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	1	4	3	4.6	1	0	25.5
48	32	0	-	0	64	0	90	0	11	1	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	4	8.1	1	0	24.2
49	26	0	-	0	52	0	90	0	6	6	2	6	24000	12	5	1.5	65	100	14.6	1.75	1	4	2	2.1	1	0	27.8
50	40	0	-	0	80	0	90	0	8	4	2	6	24000	12	200	12	65	100	14.6	1.75	0	0	3	4.6	2.5	7.5	41.1
51	40	0	-	0	80	0	90	0	8	4	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	3	4.6	1	0	23.8
52	31	0	-	0	62	0	90	0	11	1	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	4	8.1	1	0	24.2
53	31	0	-	0	62	0	90	0	11	1	2	6	24000	12	200	12	65	50	7.28	0.87	0	0	4	8.1	3.2	11	44.4
54	30	0	-	0	75	0	90	0	7	5	2	6	24000	12	10	3	65	25	3.64	0.44	0	0	4	8.1	1	0	28.8
55	30	0	-	0	75	0	90	0	7	5	2	6	24000	12	300	12	65	100	14.6	1.75	0	0	4	8.1	4	15	52.4
56	30	0	-	0	45	0	90	0	10	2	2	6	24000	12	200	12	65	70	10.2	1.22	0	0	5	12.0	4.4	15	52.7
57	30	0	-	0	45	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	5	12.0	1	0	28.3
58	21	0	-	0	42	0	90	0	11	1	2	6	24000	12	5	1.5	65	25	3.64	0.44	1	4	3	4.6	1	0	24.6
59	20	0	-	0	40	0	90	0	10	2	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	4	8.1	1	0	25.0
60	21	0	-	0	42	0	90	0	11	1	2	6	24000	12	5	1.5	65	25	3.64	0.44	0	0	5	12.0	1	0	27.4

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 23a: Data and rating values for Highway 54.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
1	54	N 38-13.290	W 92-37.550	20	4.0	90	12	2	6	1.5	9	3	3	1	3	1	3	3	2	1	3	0	0	1	3	40.5
2	54	N 38-13.290	W 92-37.550	25	5.0	90	12	2.5	7.5	2	12	1.5	7.5	1	3	3	9	3	2	2	6	0	0	1.5	4.5	57.8
3	54	N 38-13.423	W 92-37.527	40	8.0	75	9	2	6	2.5	15	2	6	2	6	3	9	2	5	3	9	0	0	1	3	63.4
4	54	N 38-13.423	W 92-37.527	40	8.0	75	9	2.5	7.5	2.5	15	2	6	3	9	3	9	3	2	2	6	0	0	1	3	62.6
5	54	N 38-13.820	W 92-37.348	30	6.0	80	10	4	12	4	24	0.5	10.5	4	12	4	12	3	2	1	3	0	0	2	6	82.2
6	54	N 38-13.820	W 92-37.348	35	7.0	80	10	4	12	2	12	1	9	2.5	7.5	4	12	2	5	2	6	0	0	1	3	69.7
7	54	N 38-14.816	W 92-35.697	48	9.6	85	11	1.5	4.5	1	6	3	3	1	3	2	6	4	1	1	3	0	0	1	3	41.9
8	54	N 38-15.023	W 92-35.516	35	7.0	90	12	3	9	3.5	21	1	9	1	3	2	6	3	2	3	9	0	0	1	3	68.0
9	54	N 38-15.106	W 92-35.455	30	6.0	90	12	4	12	3	18	1	9	2	6	3	9	2	5	2	6	0	0	1	3	71.7
10	54	N 38-15.205	W 92-35.388	25	5.0	90	12	4	12	4	24	0.5	10.5	4	12	4	12	4	1	3	9	0	0	1	3	83.8
11	54	N 38-30.043	W 92-16.038	30	6.0	90	12	4	12	4	24	0.5	10.5	3.5	10.5	4	12	4	1	1	3	0	0	1	3	78.4
12	54	N 38-30.043	W 92-16.038	30	6.0	85	11	4	12	4	24	0.5	10.5	4	12	4	12	3	2	1	3	0	0	1	3	80.1
13	54	N 38-31.359	W 92-13.742	35	7.0	90	12	4	12	3.5	21	1	9	3	9	4	12	3	2	0	0	0	0	1	3	73.0
14	54	N 38-31.359	W 92-13.742	35	7.0	80	10	4	12	3	18	1.5	7.5	4	12	4	12	5	0	2	6	0	0	1	3	73.4
15	54	N 38-31.459	W 92-13.607	25	5.0	85	11	4	12	3	18	1	9	4	12	4	12	2.5	3	1	3	0	0	1	3	73.9
16	54	N 38-31.49	W 92-13.607	15	3.0	90	12	4	12	4	24	1	9	4	12	4	12	1	8	1	3	0	0	1	3	82.1
17	54	N 38-31.549	W 92-13.489	25	5.0	85	11	4	12	4	24	1	9	4	12	4	12	3.5	1	1	3	0	0	1	3	77.3
18	54	N 38-31.449	W 92-12.540	30	6.0	90	12	4	12	4	24	1	9	3.5	10.5	3.5	10.5	5	0	1	3	0	0	1	3	75.5
19	54	N 38-31.449	W 92-12.540	15	3.0	90	12	4	12	4	24	1	9	4	12	4	12	5	0	1	3	0	0	1	3	75.5
20	C54	N 38-32.195	W 92-19.952	18	3.6	90	12	3	9	3	18	0.5	10.5	3	9	3	9	1	8	2	6	0	0	1	3	73.9
21	C54	N 38-32.724	W 92-16.674	22	4.4	90	12	3	9	4	24	1	9	3.5	10.5	3	9	1.5	6	1	3	0	0	1	3	75.5
22	C54	N 38-32.847	W 92-16.093	15	3.0	90	12	4	12	3	18	1	9	3	9	4	12	1	8	1	3	0	0	1	3	74.6
23	C54	N 38-32.847	W 92-16.093	15	3.0	90	12	3	9	3	18	1	9	3	9	3	9	1	8	1	3	0	0	1	3	69.6

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 23a: Data and rating values for Highway 54 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
1	23	0	-	0	35	0	90	0	11	1	2	6	13000	7.8	10	3	70	150	11	1.32	0	0	3	4.6	1	0	19.8
2	20	0	-	0	30	0	90	0	12	0	2	6	13000	7.8	10	3	70	150	11	1.32	0	0	3	4.6	1	0	19.0
3	25	2	0	0	40	0	75	4.5	13	0	2	6	13000	7.8	5	1.5	70	300	22	2.64	1	4	2	2.1	1	0	23.2
4	22	3.2	0	0	33	0	75	4.5	12	0	2	6	13000	7.8	10	3	70	300	22	2.64	0	0	3	4.6	1	0	24.1
5	25	2	0	0	36	0	80	9	12	0	2	6	13000	7.8	150	12	70	350	25.6	3.08	0	0	3	4.6	4.2	15	48.7
6	25	2	0	0	36	0	80	9	10	2	2	6	13000	7.8	10	3	70	250	18.3	2.2	0	0	2	2.1	1	0	25.9
7	25	2	1	4	25	2	85	12	13	0	2	6	13000	7.8	10	3	70	500	36.6	4.4	1.5	6	4	8.1	1	0	41.9
8	25	0	-	0	36	0	90	0	12	0	2	6	13000	7.8	60	12	70	200	14.7	1.76	0	0	3	4.6	1.7	3.3	30.2
9	25	0	-	0	35	0	90	0	12	0	2	6	13000	7.8	60	12	70	250	18.3	2.2	0	0	2	2.1	1.7	3.6	28.7
10	25	0	-	0	36	0	90	0	12	0	2	6	13000	7.8	100	12	70	300	22	2.64	0	0	4	8.1	2.8	8.9	39.3
11	27	0	-	0	27	1.2	90	0	12	0	2	6	13000	7.8	40	12	70	350	25.6	3.08	0	0	4	8.1	1.5	2.4	34.2
12	23	2.8	0	0	33	0	85	12	14	0	2	6	13000	7.8	150	12	70	500	36.6	4.4	1.5	6	3	4.6	4.5	15	57.1
13	15	0	-	0	15	6	90	0	11	1	2	6	24000	12	60	12	70	450	60.9	7.31	2	8	3	4.6	4	15	62.4
14	2	11.2	2.5	10	1	12	80	9	13	0	2	6	24000	12	120	12	70	450	60.9	7.31	1	4	5	12.0	120	15	87.0
15	18	4.8	0	0	18	4.8	85	12	11	1	2	6	24000	12	60	12	70	300	40.6	4.87	1	4	2.5	3.3	3.3	12	60.7
16	5	8	-	0	2.5	11	90	0	1	11	2	6	24000	12	30	9	70	150	20.3	2.44	2	8	1	0.6	12	15	71.7
17	14	6.4	1	4	7	9.2	85	12	11	1	2	6	24000	12	50	12	70	300	40.6	4.87	0	0	3.5	6.3	7.1	15	70.9
18	17	0	-	0	17	5.2	90	0	10	2	2	6	24000	12	40	12	70	300	40.6	4.87	2	8	5	12.0	2.4	6.8	58.5
19	8	5.6	-	0	4	10	90	0	2	10	2	6	24000	12	60	12	70	300	40.6	4.87	0	0	5	12.0	15	15	75.7
20	20	0	-	0	30	0	90	0	12	0	1	12	3000	1.8	40	12	60	400	15.8	1.89	1	4	1	0.6	1.3	1.7	28.6
21	19	0	-	0	30	0	90	0	12	0	1	12	3000	1.8	40	12	60	300	11.8	1.42	0	0	1.5	1.3	1.3	1.7	25.4
22	19	0	-	0	30	0	90	0	12	0	1	12	3000	1.8	75	12	60	250	9.86	1.18	1	4	1	0.6	2.5	7.5	33.9
23	19	0	-	0	30	0	90	0	11	1	1	12	3000	1.8	45	12	60	400	15.8	1.89	0	0	1	0.6	1.5	2.5	26.9

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 23b: Data and rating values for Highway 54.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
24	54	N 38-36.866	W 92-08.120	45	9.0	90	12	4	12	3.5	21	1.5	7.5	1	3	4	12	2	5	1	3	0	0	1	3	73.0
25	54	N 38-37.114	W 92-07.976	42	8.4	90	12	4	12	3	18	1	9	4	12	4	12	4	1	2	6	0	0	1	3	77.9
26	54	N 38-37.114	W 92-07.976	40	8.0	90	12	3.5	10.5	3	18	1.5	7.5	4	12	3	9	3	2	0	0	0	0	1	3	68.8
27	54	N 38-37.114	W 92-07.976	40	8.0	90	12	3.5	10.5	3	18	2	6	2	6	3	9	2.5	3	0	0	0	0	1	3	63.5
28	54	N 38-37.309	W 92-07.813	20	4.0	90	12	4	12	4	24	1	9	4	12	4	12	1	8	0	0	0	0	1	3	80.5
29	54	N 38-37.601	W 92-07.630	18	3.6	90	12	4	12	4	24	1	9	4	12	4	12	1	8	0	0	0	0	1	3	80.1
30	54	N 38-37.789	W 92-07.448	18	3.6	9	0	4	12	4	24	1	9	4	12	4	12	2	5	0	0	0	0	1	3	67.2

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering, SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face, DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 23b: Data and rating values for Highway 54 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
24	23	0	-	0	46	0	90	0	12	0	2	6	20000	12	70	12	70	400	45.1	5.41	0	0	2	2.1	1.5	2.6	33.9
25	23	0	-	0	33	0	90	0	12	0	2	6	20000	12	60	12	70	350	39.5	4.73	0	0	4	8.1	1.8	4.1	39.8
26	17	0	-	0	17	5.2	90	0	12	0	2	6	20000	12	40	12	70	250	28.2	3.38	1	4	3	4.6	2.4	6.8	46.1
27	10	4	-	0	10	8	90	0	12	0	2	6	20000	12	10	3	70	200	22.5	2.71	1	4	2.5	3.3	1	0	35.8
28	10	4	-	0	10	8	90	0	12	0	2	6	20000	12	45	12	70	300	33.8	4.06	0	0	1	0.6	4.5	15	53.9
29	12	2.4	-	0	12	7.2	90	0	12	0	2	6	20000	12	30	9	70	350	39.5	4.73	0	0	1	0.6	2.5	7.5	42.5
30	14	0.8	-	0	21	3.6	90	0	12	0	2	6	20000	12	40	12	70	250	28.2	3.38	0	0	2	2.1	1.9	4.5	37.8

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 24a: Data and rating values for Highways 67, 72, 8, W, 30, 110.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
1	67	N 37-31.445	W 90-18.487	40	8.0	90	12	2	6	1	6	2	6	2	6	2	6	2	5	0	0	0	0	0	0	45.4
2	67	N 37-31.445	W 90-18.487	45	9.0	75	9	4	12	1	6	1.5	7.5	4	12	3	9	2	5	1	3	0	0	0	0	60.0
3	67	N 37-36.372	W 90-20.340	20	4.0	70	8	2.5	7.5	0	0	3	3	4	12	3	9	1	8	0	0	0	0	0	0	42.9
4	67	N 37-36.372	W 90-20.340	25	5.0	90	12	3	9	1	6	3	3	2	6	3	9	1.5	6	0	0	2	8	0	0	54.8
5	72	N 37-33.846	W 90-16.092	35	7.0	90	12	4	12	2	12	2	6	4	12	4	12	1.5	6	1	3	2	8	0	0	76.4
6	72	N 37-33.846	W 90-16.092	22	4.4	90	12	4	12	2	12	1.5	7.5	4	12	4	12	1.5	6	1	3	0	0	3	9	76.5
7	72	N 37-33.967	W 90-21.687	33	6.6	90	12	2	6	2	12	3	3	4	12	2.5	7.5	3	2	1	3	0	0	0	0	53.4
8	72	N 37-33.967	W 90-21.687	20	4.0	90	12	2	6	1.5	9	3	3	4	12	2	6	2.5	3	1	3	0	0	0	0	48.4
9	72	N 37-33.982	W 90-21.978	30	6.0	90	12	3	9	1	6	4	0	3	9	3	9	5	0	1	3	0	0	0	0	45.0
10	72	N 37-33.967	W 90-21.978	20	4.0	90	12	4	12	4	24	1	9	4	12	4	12	1.5	6	1	3	0	0	0	0	78.4
11	8	N 37-51.769	W 90-54.110	40	8.0	90	12	4	12	4	24	0.5	10.5	3	9	4	12	2	5	0	0	0	0	1	3	79.7
12	8	N 37-51.769	W 90-54.110	60	12.0	90	12	4	12	4	24	0.5	10.5	4	12	4	12	4	1	0	0	0	0	1	3	82.2
13	8	N 37-51.743	W 90-34.494	40	8.0	60	6	4	12	4	24	0.5	10.5	2	6	4	12	2.5	3	2	6	0	0	1	3	76.0
14	8	N 37-51.743	W 90-34.494	40	8.0	60	6	4	12	4	24	0.5	10.5	3	9	4	12	4	1	2	6	0	0	1	3	76.3
15	8	N 37-51.773	W 90-35.236	30	6.0	90	12	1	3	1	6	3	3	0.5	1.5	1	3	3	2	0	0	0	0	1	3	33.4
16	8	N 37-51.773	W 90-35.236	25	5.0	90	12	1	3	1	6	3	3	0.5	1.5	1	3	3	2	0	0	0	0	1	3	32.6
17	8	N 37-52.095	W 90-37.080	30	6.0	55	5	4	12	4	24	1	9	4	12	3	9	5	0	1	3	0	0	1	3	69.7
18	8	N 37-52.095	W 90-37.080	25	5.0	60	6	4	12	4	24	0.5	10.5	4	12	4	12	3	2	1	3	0	0	1	3	75.1
19	W	N 38-29.369	W 90-37.897	3	0.6	90	12	4	12	4	24	0.5	10.5	4	12	3	9	3	2	1	3	0	0	1	3	73.9
20	W	N 38-29.369	W 90-37.897	25	5.0	90	12	3.5	10.5	4	24	1	9	3	9	3	9	3	2	1	3	0	0	1.5	4.5	74.1
21	30	N 38-24.492	W 90-35.153	20	4.0	90	12	1	3	0.5	3	3	3	0.5	1.5	1	3	5	0	0	0	0	0	1	3	27.6
22	30	N 38-24.492	W 90-35.153	8	1.6	90	12	2	6	2	12	2	6	1	3	2	6	5	0	1	3	0	0	1	3	44.3
23	110	N 38-08.618	W 90-31.902	25	5.0	90	12	3	9	3.5	21	1.5	7.5	3	9	3	9	1.5	6	2	6	0	0	1	3	73.5

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering,
SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face,
DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 24a: Data and Rating values for Highways 67, 72, 8, W, 30, 110 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
1	23	2.8	1.5	6	35	0	90	0	10	2	1	12	2000	1.2	10	3	50	350	11	1.33	0	0	2	2.1	1	0	23.1
2	25	2	2	8	30	0	75	4.5	10	2	3	3	7000	4.2	20	6	65	250	7.08	0.85	1.5	6	2	2.1	1	0	29.3
3	10	8	2	8	15	6	70	2	12	0	2	6	7000	4.2	22	6.6	65	400	17	2.04	0	0	1	0.6	1.5	2.3	35.3
4	20	0	-	0	20	4	90	0	12	0	2	6	7000	4.2	30	9	65	400	17	2.04	1	4	1.5	1.3	1.5	2.5	27.9
5	20	0	-	0	20	4	90	0	12	0	1	12	2000	1.2	30	9	60	350	9.21	1.1	0	0	1.5	1.3	1.5	2.5	26.3
6	20	0	-	0	20	4	90	0	12	0	1	12	2000	1.2	40	12	60	250	6.58	0.79	0	0	1.5	1.3	2	5	31.0
7	20	0	-	0	20	4	90	0	12	0	1	12	2000	1.2	20	6	60	650	17.1	2.05	0	0	3	4.6	1	0	24.9
8	22	0	-	0	33	0	90	0	12	0	1	12	2000	1.2	15	4.5	60	650	17.1	2.05	0	0	2.5	3.3	1	0	19.2
9	22	0	-	0	33	0	90	0	10	2	1	12	2000	1.2	40	12	60	200	5.26	0.63	0	0	5	12.0	1.2	1.1	34.2
10	26	0	-	0	26	1.6	90	0	12	0	1	12	2000	1.2	30	9	60	200	5.26	0.63	0	0	1.5	1.3	1.2	0.8	22.2
11	22	3.2	1.5	6	22	3.2	90	0	12	0	1	12	8000	4.8	50	12	55	600	68.9	8.26	0	0	2	2.1	2.3	6.4	45.5
12	19	4.4	1.5	6	30	0	90	0	12	0	1	12	8000	4.8	30	9	55	1500	172	12	1	4	4	8.1	1	0	45.7
13	21	3.6	0.5	2	30	0	60	4	12	0	1	12	8000	4.8	40	12	55	1000	115	12	2	8	2.5	3.3	1.3	1.7	48.4
14	12	7.2	3	12	12	7.2	60	4	12	0	1	12	8000	4.8	50	12	55	1000	115	12	0.5	2	4	8.1	4.2	15	76.6
15	15	0	-	0	30	0	90	0	12	0	1	12	8000	4.8	5	1.5	55	600	68.9	8.26	0	0	3	4.6	1	0	26.0
16	15	0	-	0	30	0	90	0	12	0	1	12	8000	4.8	5	1.5	55	600	68.9	8.26	0	0	3	4.6	1	0	26.0
17	18	4.8	2	8	27	1.2	55	5	12	0	1	12	8000	4.8	50	12	55	800	91.8	11	1	4	5	12.0	1.9	4.3	60.9
18	15	6	1.5	6	22	3.2	60	4	12	0	1	12	8000	4.8	50	12	55	800	91.8	11	0	0	3	4.6	2.3	6.4	54.6
19	23	0	-	0	33	0	90	0	12	0	1	12	3000	1.8	75	12	55	200	8.61	1.03	0	0	3	4.6	2.3	6.4	32.6
20	23	0	-	0	33	0	90	0	12	0	1	12	3000	1.8	60	12	55	200	8.61	1.03	0	0	3	4.6	1.8	4.1	30.3
21	25	2	0.5	2	20	4	90	0	12	0	2	6	6000	3.6	5	1.5	60	600	23.7	2.84	0	0	5	12.0	1	0	25.7
22	40	0	-	0	80	0	90	0	12	0	2	6	6000	3.6	20	6	60	600	23.7	2.84	0	0	5	12.0	1	0	25.4
23	23	0	-	0	46	0	90	0	12	0	1	12	5000	3	15	4.5	50	500	39.5	4.73	0	0	1.5	1.3	1	0	21.3

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters

Table 24b: Data and rating values for Highways 110, Ex, 61, 55.

SN	HY	Latitude	Longitude	SH	R	SA	R	RFI	R	W	R	SF	R	FI	R	FL	R	BS	R	WF	R	DA	R	KF	R	Risk
24	110	N 38-08.618	W 90-31.902	40	8.0	90	12	2.5	7.5	2	12	2	6	2	6	3	9	1.5	6	1	3	0	0	1	3	61.0
25	110	N 38-08.329	W 90-30.412	25	5.0	90	12	4	12	4	24	1	9	2	6	3	9	0.5	10	1	3	0	0	1	3	78.0
26	110	N 38-08.329	W 90-30.412	25	5.0	90	12	4	12	4	24	1	9	3	9	2	6	1	8	0	0	0	0	1	3	73.8
27	Ex	N 38-11.674	W 90-24.021	45	9.0	90	12	3	9	2.5	15	2	6	2.5	7.5	2	6	3	2	2	6	0	0	1	3	63.4
28	Ex	N 38-11.674	W 90-24.021	45	9.0	90	12	2	6	2	12	2	6	1.5	4.5	2	6	3	2	1	3	0	0	1	3	53.4
29	61	N 38-09.475	W 90-21.355	45	9.0	90	12	3	9	3	18	1.5	7.5	3	9	3	9	3	2	1	3	0	0	0	0	65.4
30	61	N 38-09.475	W 90-21.355	45	9.0	85	11	3	9	3.5	21	1.5	7.5	4	12	3	9	3	2	1	3	0	0	0	0	69.6
31	55	N 38-09.429	W 90-21.444	55	11.0	85	11	4	12	2	12	2	6	1	3	3	9	3	2	0	0	0	0	1	3	58.0
32	55	N 38-09.429	W 90-21.444	55	11.0	85	11	4	12	2	12	2	6	1	3	3	9	3	2	0	0	0	0	1	3	58.0
33	55	N 38-09.300	W 90-21.372	25	5.0	90	12	4	12	4	24	0.5	10.5	2	6	3.5	10.5	2.5	3	2	6	0	0	1	3	77.3

SN = Site Number, HYW= Highway, SH = Slope Height, SA = Slope Angle, RFI = Rock face Instability, W = Weathering,
SF = Strength Factor, FI = Face Irregularities, FL = Face Looseness, BS = Block Size, WF = Water On The Face,
DA = Discontinuities adversity, KF = Karst Factor, R = Rating, and Risk = Risk Value for all rating parameters

Table 24b: Data and rating values for Highways 110, Ex, 61, 55 (continued).

SN	DW	R	DS	R	DV	R	SA	R	SW	R	NOL	R	ADT	R	ERQ	R	PSL	RCL	AVR%	R	DSD	R	BS	R	AF	R	Conseq.
24	23	0	-	0	46	0	90	0	10	2	1	12	5000	3	10	3	50	500	39.5	4.73	0	0	1.5	1.3	1	0	21.7
25	20	0	-	0	40	0	90	0	12	0	1	12	5000	3	30	9	50	500	39.5	4.73	0	0	0.5	0.3	1	0	24.2
26	20	0	-	0	40	0	90	0	11	1	1	12	5000	3	30	9	50	500	39.5	4.73	0	0	1	0.6	1	0	25.3
27	15	6	0.5	2	45	0	90	0	8	4	1	12	5000	3	20	6	50	600	47.3	5.68	0	0	3	4.6	1	0	32.8
28	15	6	0.5	2	45	0	90	0	8	4	1	12	5000	3	20	6	50	600	47.3	5.68	1	4	3	4.6	1	0	35.8
29	6	9.6	3	12	3	11	90	0	10	2	1	12	5000	3	20	6	55	300	21.5	2.58	1	4	3	4.6	6.7	15	65.5
30	6	9.6	3	12	3	11	85	12	10	2	1	12	5000	3	20	6	55	300	21.5	2.58	1	4	3	4.6	6.7	15	74.6
31	19	4.4	2	8	19	4.4	85	12	12	0	2	6	14000	8.4	20	6	70	600	47.3	5.68	1.5	6	3	4.6	1.1	0.3	49.9
32	20	4	1.5	6	30	0	85	12	12	0	2	6	14000	8.4	60	12	70	600	47.3	5.68	2	8	3	4.6	2	5	55.5
33	24	0	-	0	36	0	90	0	12	0	2	6	14000	8.4	75	12	70	300	23.7	2.84	0	0	2.5	3.3	2.1	5.4	32.5

SN = Site Number, DW = Ditch Width, DS = Ditch Shape, DV= Ditch Volume, SA = Slope Angle, SW = Shoulder Width, NOL = Number Of Lanes, ADT = Average Daily Traffic, ERQ = Expected Rock fall Quantity, PSL = Posted Speed Limit, RCL = Rock Cut Length, AVR % = Average Vehicle Risk, DSD = Decision Sight Distance, BS = Block Size, AF = Adjustment Factor, R = Rating, and Conseq. = Consequence value for all rating parameters