Maerz, N. H., Youssef, A., and Lauer, R., 2004. MORFH RS: A rockcut rating system for Missouri highways. 55th Highway Geology Symposium, Kansas City, Missouri, Sep. 7-10, 2004, pp 406-424.

MORFH RS: A ROCKCUT RATING SYSTEM FOR MISSOURI HIGHWAYS

NORBERT H. MAERZ

AHMED YOUSSEF

University of Missouri-Rolla, 1006 Kingshighway, Rolla, MO, 65409-0660.

ROBERT LAUER

Missouri Department of Transportation, 1590 Woodlake Drive, Chesterfield, MO, 63017-5712

The Missouri Rock Fall Hazard Rating System (MORFH RS), a risk/consequence based classification system has recently been completed. The system was specially developed for Missouri, which tends to have low but highly weathered cuts, with special problems from highly weathered karst features such as filled sinkholes.

MORFH RS utilizes mobile video imaging for primary screening of rock cuts. Rock cuts identified as potentially problematic are assigned for further evaluation. Images of the rock cut, taken from the video, are used to make measurements of rock cut parameters such as slope height, slope angle, ditch width, ditch depth, potential rock fall quantity, and shoulder width, and other parameters required for the rating. Other properties such as face looseness, instability, weathering, strength, block size need to be assessed by field inspection, for the problematic cuts only. Location information is obtained from a GPS receiver. Rock cut locations, attributes, hazard ratings, digital photographs, GPS coordinates, and other data are presented in a single page report.

MORPH RS then calculates a risk and a consequence rating, based on the measured and assessed parameters. Separating risk and consequence of failure is important because sometimes high risk and low consequence can be tolerated more than low risk and high consequence. In addition, some parameters such as block size are used in both the risk and consequence ratings: Larger block size decreases the risk of failure, but increases the consequence.

MORPH RS, during development, has been used to analyze over 500 Missouri rock cuts. Over 300 cuts were analyzed in detail and are ranked according to risk and consequence. These results can be used by the Department of Transport to prioritize remediation. A simulation has been conducted that shows the relative merits of various forms of remediation treatments.

1. INTRODUCTION

The Missouri Rock Fall Hazard Rating System (MORFH RS) has been developed for Missouri Highways. Missouri Highway rock cuts tend to be relatively low in most cases, often old and/or highly weathered. There are special problems associated with the many weathered karst features, such as filled sinkholes. For this reason and others, existing rock hazard systems were inadequate for Missouri needs. The MORFH RS system was first described in Maerz et al (2003), and is more fully described in Maerz et al. (2004).

Because roads and highways cover hundreds of thousands of miles of highly variable geological terrain, maintaining rock cuts presents a special challenge to geologists and geotechnical engineers. It would be a prohibitive task to do a routing assessment on all the rock cuts. Consequently State Departments of Transports (DOT's) have in the past been reactive to rock cut problems rather than proactive.

More recently several rock fall hazard rating systems have been proposed and implemented by several DOT's in the USA (Youssef et. al., 2003). MORFH RS is a response to the needs of the DOT's and an improvement to existing rating systems.

MORFH RS provides three components, which makes it highly effective:

1. Highway rock cuts are pre-screened to determine which ones need closer examination, by examining video highway logs.
2. The rating system is based on a risk of failure / consequence of failure calculation, which allows for a more informed decision making process.
3. Many of the parameters needed for the rating systems and can be measured on the video images.

2. MORPH RS

2.1 Mobile video screening

MORFH RS is based on mobile highway video technology, which means that highway rock cuts can be routinely imaged (video logged) at highway speeds by technicians, and the video can be replayed at the office where engineers or geologists can rapidly screen the cuts and determine which need more detailed assessment. Video screening can be done using a sophisticated fully instrumented vehicle such as RoadWare's ARAN (Figure 1) (Maerz and McKenna, 1999) or as simple as a video camera mounted in a car or truck (Figure 2) (Maerz et al., 2003).

Figure 1. An example of an Automatic Road Analyzer (ARAN) made by RoadWare Corporation.

Figure 2. Simple video setup.

2.2 Risk-Consequence scheme

The new Missouri rating system is predicated on separating risk (of failure) from consequence (of failure) (Figures 3, 4). While other rating systems may consider both risk of failure and consequence of failure factors, they tend to lump them together. This is incorrect, as some parameters affect risk and consequence in different ways. For instance, the larger the block size, the lower the risk of failure but the higher the consequence of failure. Or, a 90° slope would present the highest risk of failure, while perhaps a 30° slope would present the highest consequence for large rolling blocks and 85° from small bouncing blocks.

In any case, separating risk and consequence seems useful, because it may be possible to concern ourselves only with high risk, high consequence rock cuts. Low risk rock cuts need not worry us because there is small chance of failure, and low consequence cuts need not worry us because the fallen rock is not likely to reach and affect the highway traffic.

2.1.1 MORFH rating system in a nutshell

The MORFH rating system includes 23 factors, including 9 factors for risk, 10 factors for consequence, 3 adjustment factors (including 1 internally calculated value). These factors have been organized into risk (of failure) and consequence (of failure) categories, and identified based on how the factors 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 of rock cuts 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 which are obtained from the MODOT records or calculated for each section of road.
4. Conditional parameters such as adversely oriented discontinuities, karst features, ditch capacity exceedence, and the effect of bad benches, which are reflected in a conditional ditch shape parameter.

For each parameter, the input value is one of:

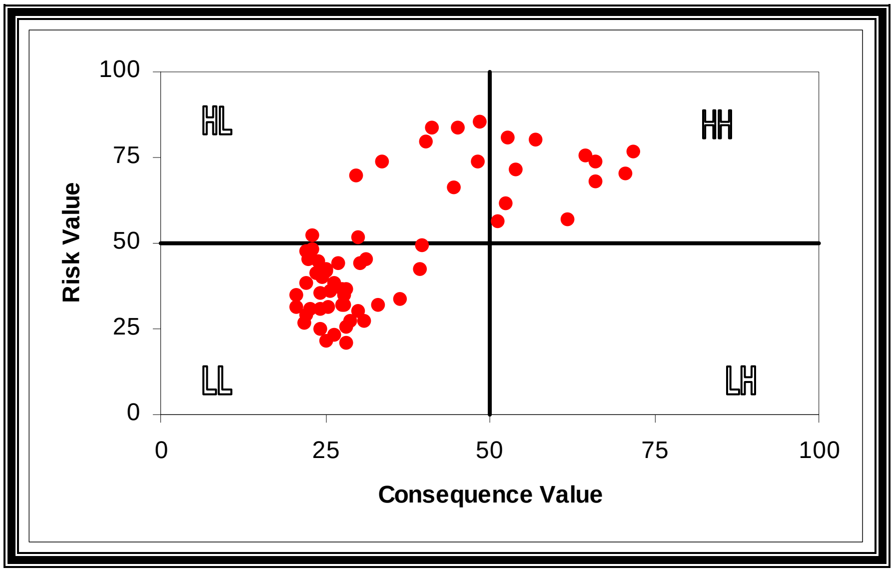
1. An actual measurement for all quantifiable parameters, either a number or a measurement in feet or degrees, where measured, estimated, or derived from a database.
2. A class number for all parameters that are not quantifiable. This is on a scale of 0 to 4. The values 0, 1, 2, 3, and 4 correspond to descriptions for each parameter in the charts below, however half ratings (e.g. 2.5) are allowed.

MORFH RS uses the above number to generate a rating value for each factor, typically between 0 and 12 as described below. The system is further described by (Maerz et al., 2004) and in Appendix 1.

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

Figure 3: Single page report shows the results of evaluation.



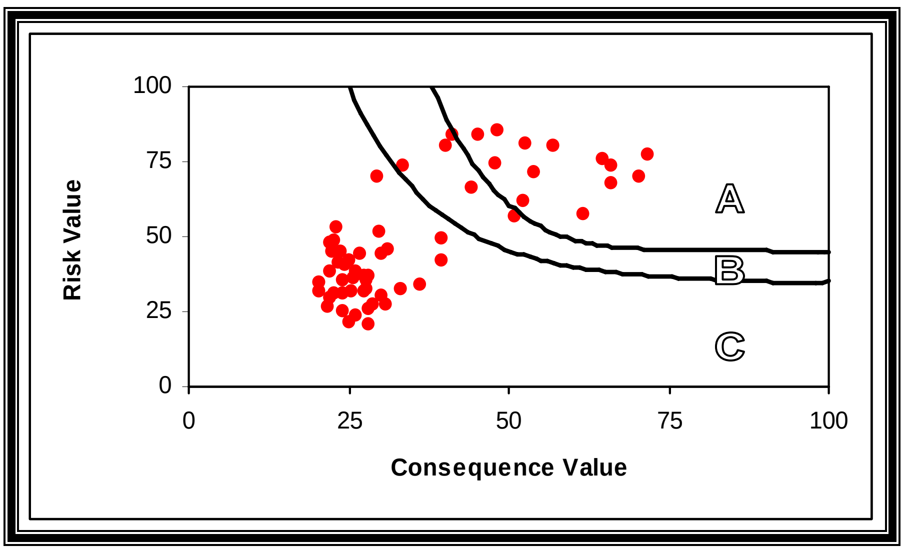


Figure 4. An example of a Risk – Consequence diagram for rock cuts from a section of highway 65 in Missouri. Top: diagram for the risk/quadrant data. LL = Low Risk Low Consequence, HL = High Risk Low Consequence, HH = High Risk, High Consequence, and LH = Low Risk High Consequence. Bottom: diagram for the zoned data. A= High Hazard Zone, B = Moderate Hazard Zone, and C = Low Hazard Zone.

2.3. Video scaled measurements

The same images that can be used for video logging and previewing can also be used to measure some of the parameters required for the rating system (Maerz et al., 2003; Youssef et al., 2004). 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 sufficiently accurate to provide input data for a rock hazard rating system.

The simple video camera setup used for video logging is set up at an angle of 10º to the right of the direction of travel, and tilted and zoomed so as to give coverage to the top of moderately high rock cuts, and the traveling lane of the highway.

The simplest way to use the system is to use a known length as a scaling object. Figure 5 shows the land width (12' in Missouri) used to set the scale. The horizontal and vertical construct lines in Figure 5 define a plane in which linear measurements are valid. The inclined dotted line is a "ditch reference line", and is used to mark the top/edge of the ditch (at road level) and the foot of the rock cut. The user uses one line to trace the face of the slope and another line to define the vertical extent of the slope. RockSee then automatically calculates the slope height and angle, and presents it in the window.

Similar calculations can be made for shoulder widths, ditch dimensions (and volumes based on a geometric model of the ditch, rectangle, triangle, or trapezoid), and potential rock fall quantities based on measuring the area of loose rock on the face, requiring an assumption of the depth of the loose rock. Other linear measures are possible as long as they are contained in the plane as defined above.

Tests were conducted to determine the accuracy of the RockSee measurements, by comparing to manual measurements. Results showed the average errors were less than 10% which is accurate enough for input into MORFH RS. The following shows the accuracy of all measurements:

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%

The RockSee program automatically enters the results of the measurements are into a database as described below.

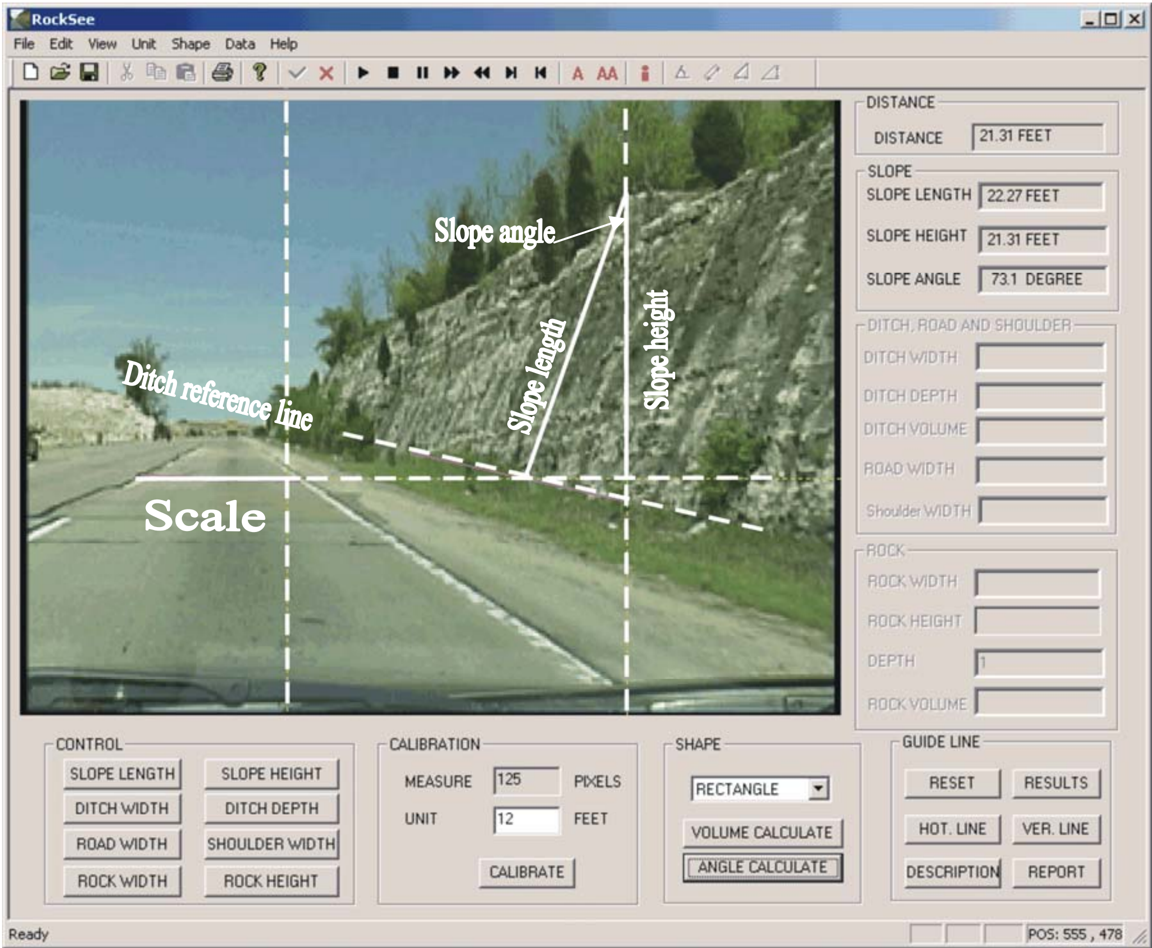


Figure 5. An example of the RockSee measurement of slope height and angle. Dotted lines are constructs, solid lines are measurements.

2.4 Field data collection

As Missouri's roads are long and numerous the use of field data sheets became tedious. A digital data collection system for the field parameters was developed as well as a GIS database management system. For the sites that needed detailed rating, a Pocket PC (Compaq IPAQ with ArcPad®) (Figure 6) was used to edit the site locations, and add the field rated parameters. The IPAQ includes an optional Navman GPS receiver to automatically record the site locations.

Communication (synchronization) with the desktop PC is handled by ActiveSync® software using USB connectivity. (ArcPad runs on desktop PC's as well as mobile computing devices).

Figure 6. Compaq IPAQ PC with ArcPad software for field data collection.

2.4 GIS implementation

ArcGIS® is the database management system that is used for the MORFG RS system. Figure 7 shows the outline of the GIS. In addition to the layer generated for rock cut sites, sorted by highway numbers (63, 44, 65, 55, 54, 70), there are layers that show the road network, the county outlines, geological map, topographic map, shaded relief, and a digital elevation model.

The attribute data is input from both the IPAQ mobile computer (rated parameter values) and from the office computer (RockSee measured parameters).

Figure 8 shows an example of data that can be retrieved from the database. Rock cut sites can be sorted, by county, by highway, by rating or other criteria. Clicking on any individual site will bring up all the attribute data, rating, and stored image if available. Other data such as maintenance records could easily be incorporated into the database.

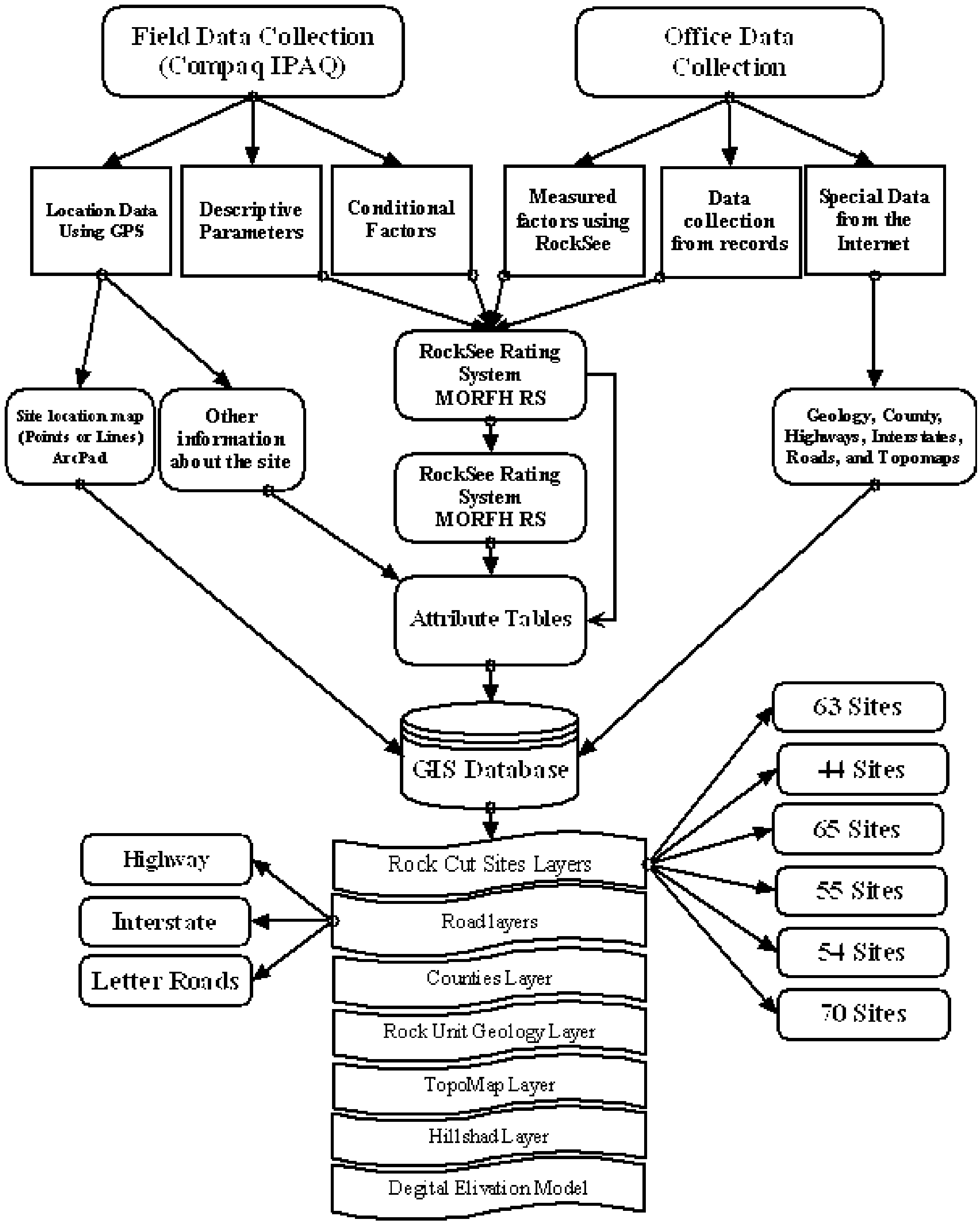


Figure 7. Database management system.

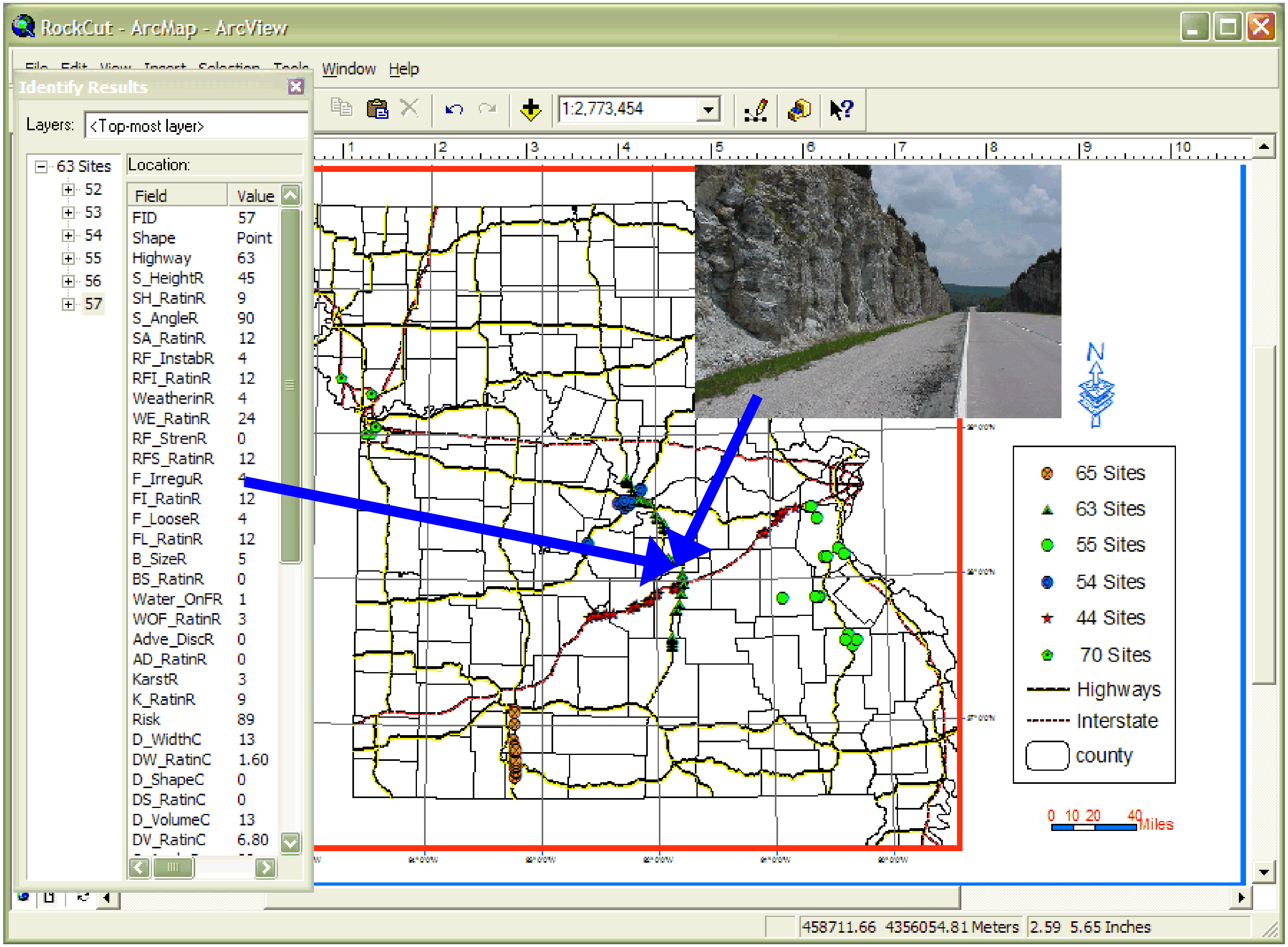


Fig. 8. Example of a GIS implementation. Map shows highways, counties, and sites. Clicking on any site brings ups an attribute table as well as an image from the database.

3. RESULTS OF INVESTIGATIONS

3.1 Missouri ratings

During the development of the systems, over 500 rock cuts in Missouri were evaluated; over 300 were given detailed ratings. Figure 9 shows some typical analysis results for four Missouri highways. Typical Missouri highways contain older rock cuts in carbonate rock with some filled sinks and sandstone rock with large block sizes, highly weathered in some areas. 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 for all of the rock cuts. Notably for the highway 65 results, there are a substantial number of low risk-low consequence cuts. These are the new cuts that have been constructed in the last few years.

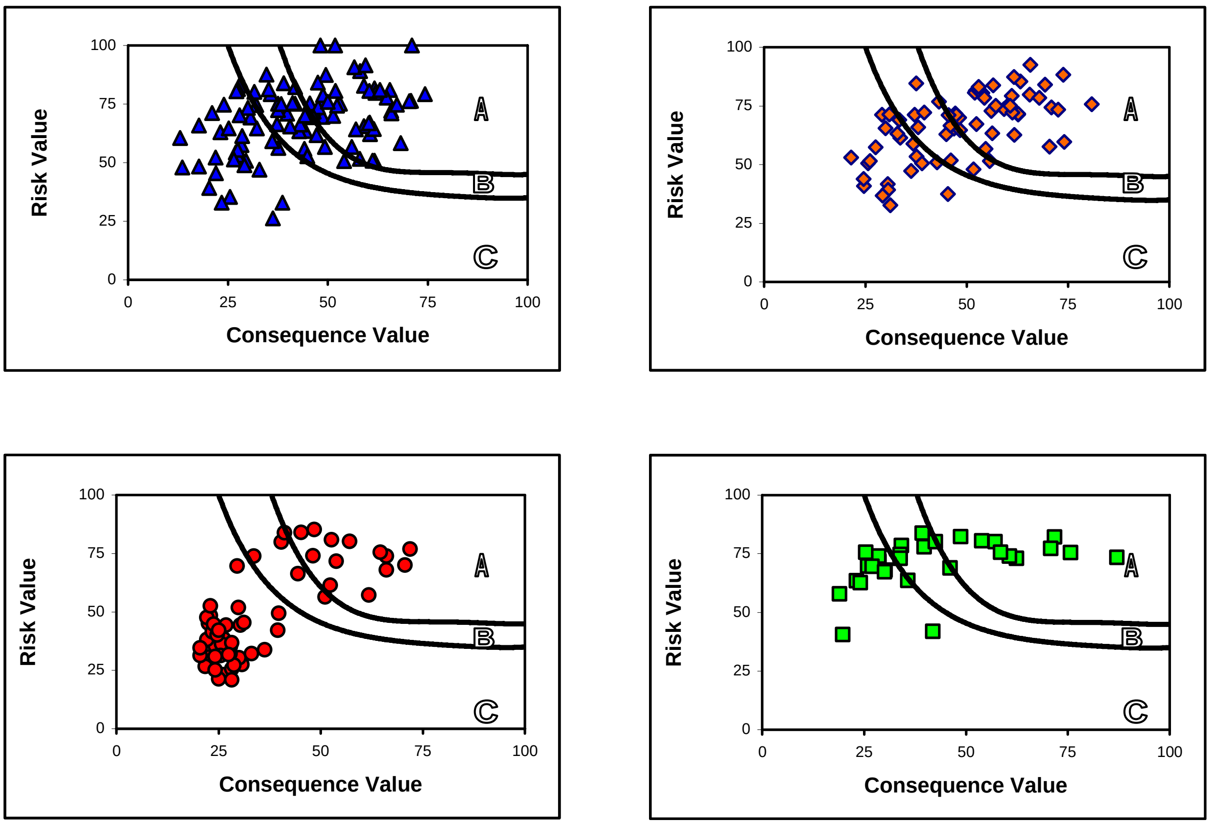


Figure 9. Results of analyses: Top left: Highway 63. Top right: Highway 44. Bottom left: Highway 65. Bottom right: Highway 54 (A= High Hazard Zone, B = Moderate Hazard Zone, and C = Low Hazard Zone).

3.2 Remediation simulations

To demonstrate the effectiveness of remediation techniques, simulations were conducted whereby the effects of scaling, ditch enhancement and trim blasting were simulated by changing the ratings of individual parameters to what they might be if the particular remedial measure was implemented. Figure 10 shows the results of the simulations.

For instance scaling decreases face instability, face looseness, face irregularity, rock fall quantity and increased ditch capacity (ditch cleaning is assumed). As a result the risk rating decreases dramatically while the consequence rating decrease slightly (Figure 10). It is noteworthy that while scaling is the least expensive solution, it is usually a short term solution.

Making ditch improvements (deepening and widening) increases the ditch width, volume, shape and effectiveness. As a result the consequence rating is dramatically reduced (Figure 10). It is however not always possible to increase the size of the ditch without removing some of the rock face.

Cutting back (trim blasting) the slope face decreases face instability, face looseness, face irregularity, rock fall quantity and can often decrease the weathering rating as new rock is exposed. At the same time it is possible and recommended to make ditch improvements increasing ditch capacity, ditch width, volume, shape and effectiveness. As a result there is a dramatic decrease in risk and consequence rating (Figure 10). This is the most costly solution, but also the most permanent, with the possible exception of the return of weathering after a number of years.

4. SUMMARY AND CONCLUSIONS

The Missouri Rock Fall Hazard Rating System (MORFH RS), a risk/consequence based classification system has recently been completed. Although designed for Missouri highways, the system can be adjusted for other jurisdictions by changing out some of the parameters, and perhaps changing the ratings for some of the parameters. In the Missouri system the emphasis has been on evaluating relatively low but highly weathered cuts, with special problems from highly weathered karst features such as filled sinkholes. In other jurisdictions there may be more of an emphasis on adversely oriented structure or other factors.

MORPH RS is very cost effective. Prescreening of video logs immediately reduces the problem of a large highway network with thousands of miles of highways to a more manageable number of rock cuts. Measurements on video images of many of the parameters needed for the rating reduces the amount of effort that must be expended in the field. Mobile computing devices link to GPS and entered into a GIS database make data transfer seamless.

The risk consequence nature of MORPH RS is a dramatic improvement in analysis, because in some cases higher risk may be tolerated while in others higher consequences. More importantly, values of parameters such as block size and slope angle have opposite effects on the risk and on the consequence rating. MORPH RS can be used to prioritize remediation, and the s effect of scaling, ditch modification, and trim blasting has been demonstrated.

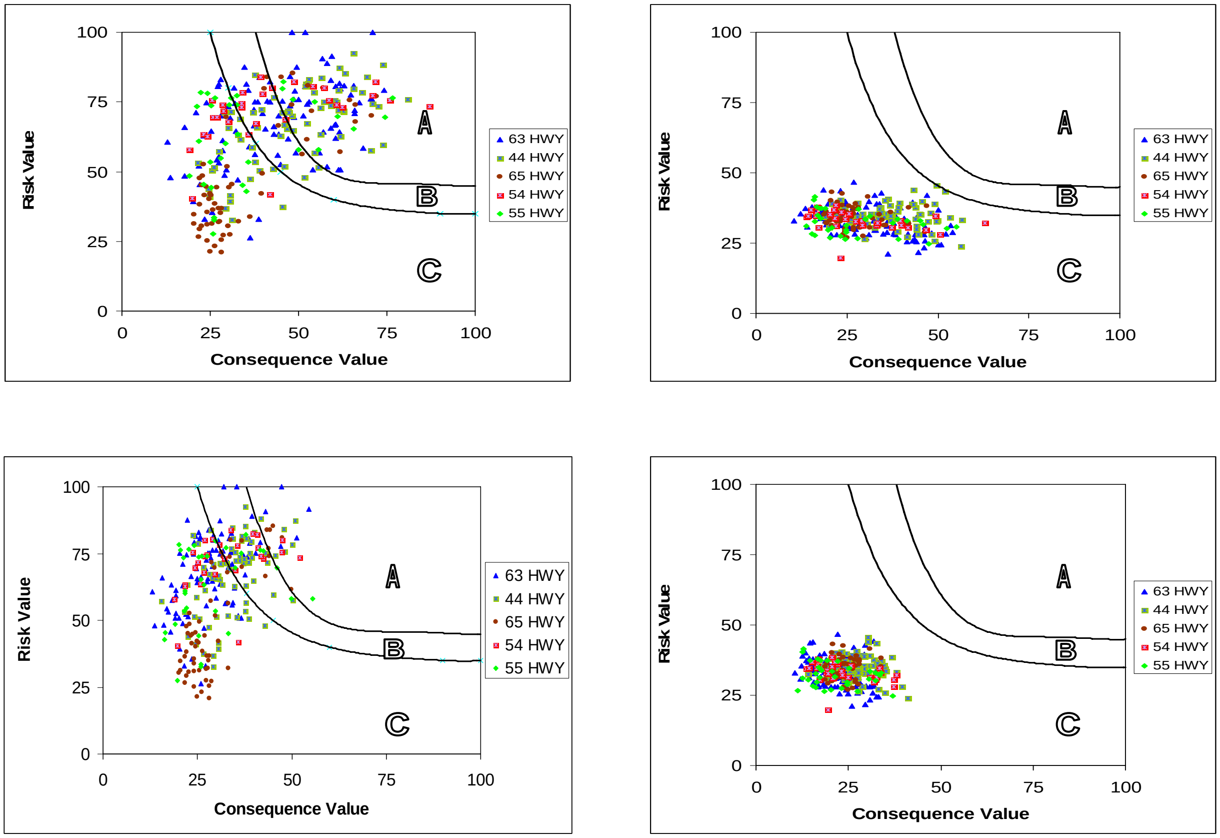


Figure 10. Results of remediation simulations: Top left: All data. Top right: Scaling. Bottom left: Ditch enhancement. Bottom right: Trim blasting. (A= High Hazard Zone, B = Moderate Hazard Zone, and C = Low Hazard Zone).

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the Missouri Department of Transportation (MODOT) and UM system Research Board for funding various aspects of this research. We would also like to thank the personnel of MODOT (Ray Purvis, Tom Fennessey, Mike Fritz, George Davis, and Alan Miller for their help and guidance with the project.

6. REFERENCES

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., and Xiang, Q., 2003. Digital imaging for screening and making measurements of features on highway rock cuts. Transportation Research Board, 82nd Annual Meeting, Washington, D.C., Jan. 12-16, 2003, 20 pp.

Maerz, N. H., Youssef, A., and Fennessey, T., 2004. New risk-consequence rock fall hazard rating system for Missouri highways using digital image analysis. Submitted to Environment and Engineering GeoScience, July, 2004.

Youssef, A., Maerz, N. H., and, Fritz, M. A., 2003. A risk-consequence rockfall hazard rating system for Missouri highways. 54th Highway Geology Symposium, Burlington, Vermont, Sep. 24-26, 2003, pp 175-195.

Youssef, A., Maerz, N. H., and Xiang, Q., 2004. RockSee: video image measurements of physical features to aid in highway rock cut characterization. Computers and Geosciences, Aug. 2004.

® ActiveSync, ArcPad, and ArcGIS are registered trademarks of xxxxxxxxxx

APPENDIX 1: MORFH RS

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

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

for risk side. **AND** for consequence side:

SA (Slope angle	20^o	30^o	40^o	50^o	60^o	70^o	80^o	85^o	90^o
(Consequence) Rating	0	12	10	6	3	2	4	12	0

RI (Rockfall instability)	**Class No.**	**Description**	**(Risk) Rating**
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

WF (Weathering factor)	**Class No.**	**Description**	**(Risk) Rating**
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

SOIR (Strength of intact rock)	**Class No.**	**Description**	**(Risk) Rating**
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

FI (Face irregularity)	**Class No.**	**Description**	**(Risk) Rating**
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

FL (Face looseness)	**Class No.**	**Description**	**(Risk) Rating**
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

BS (Block Size)	5’	2.5’	1’	0.5’
(Risk) Rating	0	4	8	12

for risk side. **AND** for consequence side:

BS (Block Size)	0.5’	1’	2.5’	5’
(Consequence) Rating	0	4	8	12

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

DW (Ditch width)	15’	10’	5’	0’
(Consequence) Rating	0	4	8	12

AND

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

for vertical slopes with no bad benches. **OR** for non-vertical slopes and bad bench(es):

(Modified) DW (Ditch width)	30’	20’	10’	0’
(Consequence) Rating	0	4	8	12

AND

DS (Ditch shape)	Large back slope (1V:4H), 14°	Moderate back slope (1V:6H), 9°	Slight back slope (1V:8H), 7°	Flat 0°
(Consequence) Rating	0	4	8	12

ERFQ (Expected rock fall quantities)	0 ft^3/ft	10 ft^3/ft	20 ft^3/ft	30 ft^3/ft	40 ft^3/ft
(Consequence)Rating	0	3	6	9	12

SW (Shoulder Width)	12’	9’	6’	3’	0’
(Consequence)Rating	0	3	6	9	12

NOL (number of lanes)	Four lanes	Three lanes	Two lanes	One lane
(Consequence) Rating	0	3	6	12

ADT (Average daily traffic)	5000 Cars / day	10000 Cars / day	15000 Cars / day	20000 Cars / day
(Consequence) Rating	3	6	9	12

AVR (Average vehicle risk)	25% (time a vehicle is in rock cut zone)	50% (time a vehicle is in rock cut zone)	75% (time a vehicle is in rock cut zone)	100% (time a vehicle is in rock cut zone)
(Consequence) Rating	3	6	9	12

DSD (Decision sight distance)	Class No.	Description	(Consequence) Rating
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

Adjustment factor **IF** applicable

AOD (Adversely oriented discontinuities)	< 20º, 90º	20 - 45º	45 - 65º	65- 90º
(Consequence) Rating	0	4	8	12

Adjustment factor **IF** applicable

KE (Karst effect)	Class No.	Description	(Consequence) Rating
Large	4	Karst features that appear on the rock cut face, width is 150’, filled by boulders and cobbles with weak materials	12
Medium	3	Karst features that appear on the rock cut face, width is 100’, filled by boulders and cobbles with weak materials	9
Small	2	Karst features that appear on the rock cut face, width is 50’, filled by boulders and cobbles or undercut with weak materials	6
Possible	1	Carbonate rocks that could possibly have karst features but are not evident on the rock cut face	3
None	0	Non-carbonate rocks (igneous, sandstone)	0

(The following is internally calculated)

ERFQ/DV (Ditch Capacity Exceedence)	1x	2x	3x	4x
Rating Value	0	5	10	15

Bench present?	Yes	No	(if yes look at the bench and faces above the bench)	
	SCORE	4	2	0
Faces above bench	Weathering	High	Low	Fresh
	Face irregularity	High	Moderate	Smooth
	Face looseness	Large	Moderate	No
Bench characteristics	Bench width	Narrow<5’	Moderate 15’	Wide >20’
	Rock on the bench	Large amount	Moderate	None
	Slope of the bench	Toward road	Horizontal	Back slope
	TOTAL SCORE: ________	(if greater than 12 then bench is considered “bad”)		

Screening calculation (from video) to determine if detailed assessment is required

Factor	Detailed assessment triggered IF
Weathering / Karst	1. A highly weathered rating on the video image, **OR** 2. Any indication of Karst (voids, filled sinks), **OR** 3. Any significant differential erosion (cut back voids, overhangs), **OR**
Face Irregularity / Face Looseness	1. A highly irregular face or a moderately irregular face high on the cut, **OR** 2. A highly loose face or a moderately loose face high on the cut, **OR**
Fallen rock in the ditch or on the cut	Significant amount of loose rock visible in the ditch, **OR**
Ditch effectiveness	Ditch effectiveness is very low (too small, too narrow), **OR**
Adversely oriented discontinuities	Indication of adversely oriented discontinuities, **OR**
Bench(es)	Presence of bench(es).
	NO Detailed assessment triggered IF
Slope height	1. Slope height less than 10’, **OR** 2. The slope height is less than the width of the ditch plus the shoulder.