The Ohio Department of Transportation
Office of Research & Development
Executive Summary Report

Development of a Rockfall Hazard Rating Matrix for the State of Ohio

Start Date: 3/1/2001

Duration: 2 years

Completion Date: 6/30/2005

Report Date: 6/30/2005

State Job Number: 14782(0)

Report Number:

Funding: $162,391

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Problem

The geology in Ohio is characterized by the presence of gently dipping, harder, more competent strata (siltstones, sandstones, limestones) alternating with softer, less competent strata (claystones, mudstones, shales). This type of stratigraphy is highly susceptible to differential weathering which results in undercutting of the competent layers by erosion of the incompetent layers. Undercutting promotes a variety of slope movements such as rockfalls, plane failures, and wedge failures that may not occur otherwise. Many of the slope failures in Ohio initiate as plane failures and wedge failures in competent strata at higher elevations and descend as rockfalls. The frequency and size of these falls depend upon joint spacing within the competent unit and the extent by which it has been undercut. The undercutting-induced failures can be quite hazardous because of their instantaneous occurrence, high speed, and occasionally large volume of rock involved. There are many road cuts in Ohio, however, where closely jointed rock units lead to rockfalls without the presence of undercutting. This study was undertaken to develop a rating matrix that could be used to rank order the slopes in terms of their hazard potential with respect to rockfalls.

Objectives

1. Identify statistically significant variables that can be used to categorize sites with respect to rockfall hazard potential.

2. Develop a rockfall hazard rating matrix for Ohio that takes into account the topographical, geological, and hydrological conditions unique to Ohio.

3. Establish procedures for collecting field, laboratory, and other data required for rank ordering the sites according to the matrix developed.

Description

One hundred and eight sites were selected for this study in such a manner that approximately equal number of sites belonged to the high, medium, and low hazard potential categories with respect to rockfalls as indicated by visual observations. Field investigations were conducted at each site to collect data regarding slope and catchment-area geometry, slope geology, size of potential rockfall blocks, hydrogeologic conditions, rockfall history, and data needed for application of Colorado Rockfall Simulation Program. In order to account for human interaction, parameters such as the overall slope length, posted speed limit, average daily traffic (ADT), and decision sight distance (DSD) were recorded. Catchment ditches at the study sites were evaluated using the Ritchie ditch criteria. Laboratory tests were performed to determine second–cycle slake durability index values for samples of weaker rock units collected from all sites where they were exposed.

The data collected were statistically analyzed to identify variables that help differentiate between slopes of varying hazard potential and to ensure that the variables used did not duplicate the information. The variables used in statistical analysis, and eventual development of the rating matrix, were divided into three distinct groups representing the geologic, slope geometric, and traffic conditions that influence rockfall hazard potential. The geologic conditions (slake durability index, amount of undercutting, rock block size, hydrologic value, and slope orientation) include variables that indicate the potential for rockfall occurrence and the size of the rockfall. If a rockfall is geologically possible, then the slope geometric conditions (slope height, slope angle, back slope angle, ditch geometry, and Ritchie score) suggest whether or not a falling rock may enter the roadway. The traffic conditions (roadway width, average daily traffic, speed limit, Oregon vehicle risk rating, and the percent decision sight distance) consider the hazard posed to vehicles. The statistical analyses performed on each group of variables included univariate, bivariate, and cluster analyses. The results of statistical analyses indicate that slope height, slope angle, and second-cycle slake durability index are the most useful variables in differentiating between slope groups exhibiting different degrees of hazard potential (low, medium, high).

Development of the Rating Matrix

For a rating system to be practical and applicable, it must be able to perform the following three tasks: (i) evaluate the potential for a rockfall to occur, (ii) evaluate the adequacy of the catchment area, and (iii) evaluate the hazard rockfalls present to vehicles on the roadway. Table 1 shows the proposed rockfall hazard rating matrix for the specific geologic conditions that exist in Ohio. It incorporates the parameters found statistically significant as well as some of the parameters included in the existing rating systems. The overall score for a site can be determined by summing up the scores of different parameters. Table 2 provides a scoring sheet for the matrix application. The matrix is best suited for slopes that are subject to differential weathering. However, it can also be used for slopes that contain only durable rocks where discontinuities play a more dominant role than differential weathering.

Hazard Potential Evaluation of Individual Sites

The matrix shown in Table 1 was used to assign rating scores to all 108 sites. According to the exponential scale, the overall scores were found to range from a high of 156.6 to a low of 22.5. For this study, all sites with rating scores greater than 100 are considered as high hazard potential sites, those with scores between 50 and 100 as moderate hazard potential sites, and those with scores less than 50 are included in the low hazard potential category. According to this categorization, 26 of the 108 sites are rated as having high hazard potential for rockfalls, 51 as moderate hazard potential, and 31 as low hazard potential. A comparison of the original and final ratings showed that of the 42% of the slopes originally ranked as being of high hazard potential were eventually ranked the same according to the matrix. Also, 86% of the moderate and 36% of the low hazard potential sites had their ratings correspond to the original rating. Figure 1 shows the distribution of the study sites rated as high, medium, and low hazard potential sites.

Conclusions & Recommendations

1. Slake durability index, slope angle, and slope height are the most important variables in differentiating between slopes with respect to rockfall hazard potential.

2. A combination of field measurements (maximum amount of undercutting, block size, slope height, slope length, slope angle, ditch width, and ditch depth), field observations (continuity/extent of discontinuities, joint roughness coefficient, hydrologic conditions, and posted speed limit), information from the Department of Transportation database (average daily traffic and posted speed limit), and laboratory testing (slake durability index) is necessary to obtain the information needed for rating purposes.

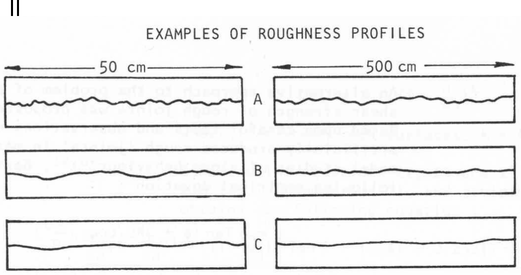
3. Among the 108 sites evaluated in this study, 26 are ranked as high hazard potential sites, 51 as moderate hazard potential sites, and 31 as low hazard potential sites.

Implementation Potential

The proposed matrix can be used to evaluate the rockfall hazard potential of all road cuts in the state of Ohio. This will help prioritize the road cuts for remediation purposes and allocate funds accordingly. This proactive approach will minimize the potential for any accidents associated with rockfalls, will be cost effective, and will help generate a rockfall-history database for all road cuts in Ohio.

Table 1: The rock fall hazard rating matrix for Ohio.

EVALUATION PARAMETERS			RATING SCORES FOR DIFFERENT CATEGORIES OF EVALUATION CRITERIA			
			3 Point/(1)	9 Points/(2)	27 Points/(3)	81 Points/(4)
GEOLOGIC PARAMETERS						
Geologic Character	Differential Weathering	Slake Durability Index	90-100%	75-90%	50-75%	<50%
		Max. Amount of Undercutting	0-1 ft	1-2 ft	2-4 ft	>4 ft
	Discontinuity Role	Discontinuity Extent/Orient.	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
		Discontinuity Surface Features	Very rough JRC=20	Rough JRC=15	Undulating JRC=10	Smooth JRC=5
Block Size/Volume of Rock Fall			1 ft/ 3 yd^3	2 ft/ 6 yd^3	3 ft/ 9 yd^3	4 ft/ 12 yd^3
Hydrologic Conditions			No water seeps on slope	A few water seeps on slope	Many water seeps on slope	Numerous water seeps on slope
GEOMETRIC PARAMETERS						
Ritchie Score			<1	1-1.5	1.5-2.5	>2.5
TRAFFIC PARAMETERS						
ADT x Slope Length / 24 hrs / Posted Speed Limit x100%			25% of time (very low)	50% of time (low)	75% of time (medium)	100% of time (high)
% Decision Sight Distance			Adequate sight distance, ≥100%	Moderate sight distance, 75%	Limited sight distance, 50%	Very limited sight distance, <50%
Pavement Width			50 feet	40 feet	30 feet	20 feet
ROCKFALL HISTORY			No falls	A few falls	Many falls	Numerous falls



Joint Roughness Coefficient

A. Rough undulating - tension joints, rough sheeting, rough bedding. JRC = 20

B. Smooth undulating - smooth sheeting, non-planar foliation, undulating bedding. JRC = 10

C. Smooth nearly planar - planar shear joints, planar foliation, planar bedding. JRC = 5

Table 2: Scoring sheet for the rock fall hazard rating matrix.

GEOLOGIC PARAMETERS					
Differential Erosion					
SDI	______	(a)	Greater Value (c or f)*	______	(g)
Maximum Amount of Undercutting	______	(b)			
Total (a + b)	______	(c)*	Block size	______	(h)
Discontinuities Role			Hydrologic	______	(i)
Discontinuity Extent/Orientation	______	(d)			
Discontinuity Surface Features	______	(e)	Total (g+h+i)/4	______	(j)
Total (d + e)	______	(f)*			
GEOMETRIC PARAMETER					
Ritchie's Score	______	(n)			
TRAFFIC PARAMETERS					
AVR	______	(o)			
% DSD	______	(p)			
Pavement Width	______	(q)			
Total (o+ p+q)/3	______	(r)			
ROCK FALL HISTORY					
History	______	(s)			
OVERALL SCORE					
Lines (j+n+r+s)	______	(t)			

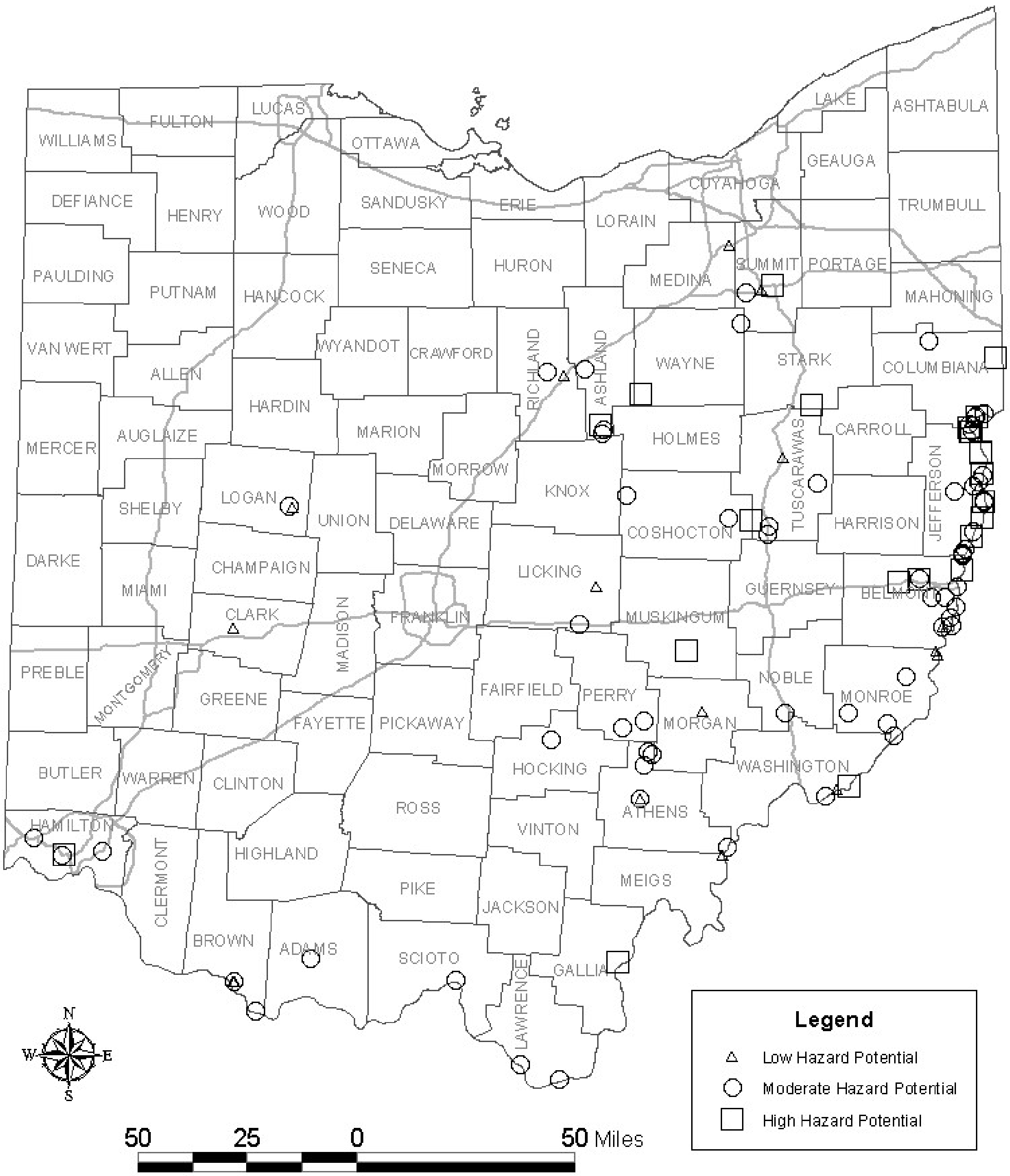


Figure 1: Distribution of study sites rated as high, medium, and low hazard potential sites.