Landslide Hazard Rating System in Ohio DOT

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Abstract
The Geotechnical Engineering Office (GEO) of the Ohio Department of Transportation (ODOT) has embarked on a concerted effort to develop a comprehensive geological hazard management system (GHMS) to enable better management of data and activities related to planning, design, construction, and maintenance projects. There are five geological hazards to be eventually included in the Ohio GHMS: rockfalls, landslides, underground mines, karst, and shoreline erosion. This paper presents the development of a landslide hazard rating system. The associated statistical and cluster analysis results of 37 Ohio landslide sites validates the effectiveness of the rating system.

Introduction

One of the missions of the GEO in ODOT is to develop and maintain a Geological Hazard Management System (GHMS) to support agencies' activities, such as planning, design, construction, and maintenance of both existing and new highway infrastructures. Specifically, the guiding requirements of the GHMS are established to encompass: (a) maintain a comprehensive inventory of geological hazards, (b) establish and enforce routine monitoring schedules, (c) create risk assessment matrix for each geological hazard type, (d) generate cost-benefit scenarios, (e) provide support to decision-making for routine prioritization, (f) provide support to construction during new development and remediation projects, (g) preserve historical hazard data, and (h) enable information exchange with diverse groups of users.

The focus of this paper will be to present the landslide hazard scoring system based on expert opinions found in literature and ODOT in-house experiences. The hazards are rated primarily for the potential impact of landslide on the safety and operation of a roadway and the adjacent properties and highway structures. The application of clustering techniques reveals that three distinct groups of landslides hazards categories could be established. The validation of the scoring system is established by a series of statistical analysis techniques, including inferential statistics and cluster analysis techniques applied to 37 landslide sites information collected as a pilot landslide database in Ohio.

ODOT Landslide Hazards Scoring System

The development of Ohio DOT landslide hazards rating matrix was based on synthesis and modification of existing systems developed at other state DOTs, including Oregon DOT, Washington DOT, New York DOT, Utah DOT, and Hong Kong Geotechnical Engineering Office. As summarized in Table 1, 23 parameters have been used by various agencies for scoring purpose. The final version of the landslide rating system adopted by Ohio DOT is shown in Table 2. The risk factors included in the ODOT landslide hazards rating system include movement location and impact on roadway, hazard to traveling public, decision sight distance, average daily traffic, accident history, and maintenance frequency and response. A separate consideration could include benefit cost ratio.

Statistical Validations

The validity of landslide hazard rating system is checked using comprehensive statistical correlation and clustering analysis techniques. The clustering technique enables the researchers to identify differences and similarities among groups of landslide sites, thus allowing grouping of landslide sites with similar risk levels. In this paper, the classifications of landslides are determined to be low, medium and high based on the potential hazard due to landslide features and its potential effects on the elements associated with roadway. The information used in determining scores of the hazard components in the scoring system is both subjective and objective involving a wide range of scales and units. In order to eliminate the effect of unit difference, a binary cluster analysis technique is used. In the binary clustering technique, there are two possible ways to characterize a parameter. If a parameter falls into a specified criterion, a numerical value of one is given. Otherwise, a numerical value of zero is assigned. The similarity comparison between two landslide sites can be made using the so-called two-way association or contingency table as shown in Table 3 and a Euclidean distance calculation given in equation below. The value obtained from the equation represents the relative similarity between two entities. As the distance between them increases, the similarity decreases.

As an example, the similarity coefficient of two landslide sites (site no. 1 and site no. 2 in Table 4) will be presented. As seen in the binary data in Table 4, the occurrence of various factors that are both present in sites no. 1 and no. 2 (1 and 1) is 2 times. The occurrence of presence and absence of various factors in sites no.1 and no. 2 (1 and 0) is 3 times. The occurrence of absence and presence of various factors in sites no.1 and no. 2 (0 and 1) is 3 times. Finally, the occurrence of the absence and absence of various factors in sites no. 1 and no. 2 (0 and 0) is 12 times. The parameters of a, b, c, and d in Table 3 are 2, 3, 3, and 12, respectively. Based on Equation 1, the similarity coefficient of sites no. 1 and no. 2 can be calculated as $D_{1,2} = \sqrt{3+3} = 2.45$.

Table 1. Summary of parameters used in various agencies' landslide numerical rating system

No.	Parameters	Hong Kong (1988)	ODOT (1992)	ODOT (2001)	NYSDOT (1988)	NYSDOT (1992)	WSDOT (1993)	The Proposed system
1	Slope Height	×	×		×	×		
2	Slope gradient	×						
3	Volume		×		×	×		
4	Average daily traffic		×	×	×	×	×	×
5	Population density							
6	Travel distance	×			×	×		×
7	Expected number of landslide fatalities for a given facility				×	×	×	
8	Decision sight distance		×		×	×	×	×
9	Risk to vehicle		×			×	×	×
10	Relative emergency							×
11	Detour time						×	
12	Expected damage					×	×	×
13	Annual maintenance cost			×			×	×
14	Failure frequency	×		×	×	×		×
15	Aspect							
16	Accident history			×			×	×
17	Benefit-cost ratio			×			×	×
18	Rate of movement							×
19	Known instability related to geology	×	×		×	×		
20	Occurrence of ground and water surface	×	×		×	×	×	
21	Impact to road structure and adjacent features	×		×			×	×
22	Vertical and horizontal of scarp of displacement			×			×	×
21	Traffic speed		×		×	×	×	×
22	Potential future impact	×				×	×	×
23	Highway classification			×			×	

Table 2. Ohio landslide hazard rating system

		RATING CRITERIA and SCORE			
CATEGORY		Points 3	Points 9	Points 27	Points 81
Movement location/ impact (select higher score)	Current and potential impact of landslide on roadway	On slope with a low potential to affect shoulder	On slope with a low potential to affect roadway	On shoulder, or on slope with a moderate potential to affect roadway	On roadway, or On slope with a high potential to affect roadway or structure
	Current and potential impact of landslide on area beyond right of way	On slope with a low potential to impact area beyond right of way (A)	On slope with moderate potential to impact area beyond right of way (B)	On slope with high potential to impact area beyond right of way (C)	On slope with high potential to impact structure beyond right of way (D)
Hazard to traveling public (Select higher score)	Rate of displacement in roadway if known	<1-inch/year	1 to 3-inches/year No single event ≥1-inch	3 to 6-inches/year No single event ≥3-inches	>6-inches/year Single event ≥3-inches
	Evidence of displacement in roadway	Visible crack or dip no vertical drop (E)	≤1-inch of displacement (F)	1 to 3-inches of displacement (G)	≥ 3-inches of displacement (H)
Maintenance (Select higher score)	Maintenance frequency	None to rare	Annually (one time/year)	Seasonal (1 to 3 times/ year)	Continuous throughout year (> 3 times/year)
	Maintenance response	No response (I)	Requires observation with periodic maintenance (J)	Requires routine maintenance response to preserve roadway (K)	Requires immediate response for safe travel or to protect adjacent structure (L)
ADT		<2000 (M)	2001-5000 (N)	5001-15000 (O)	>15001 (P)
%Decision Sight Distance (DSD)		≥ 90 (Q)	89 -50 (R)	49-35 (S)	< 34 (T)
Accident history		No accident (U)	Vehicle or property damage (V)	Injury (W)	Fatality (X)

Table 3. Contingency table of binary variables of case i and j

i/j	1	0
1	a	b
0	c	d

Table 4. Binary data of site no. 1 and no. 2

Site no.	Movement location /impact				Hazard to traveling public				Maintenance frequency/response				ADT				Decision sight distance			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0
2	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0

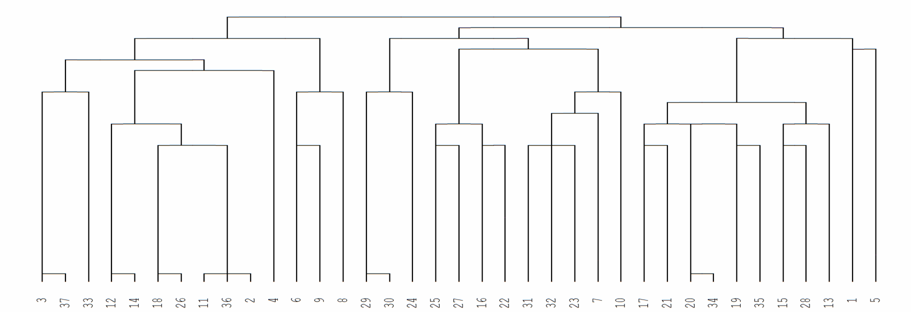

Figure 1. Tree diagram of 37 landslide sites

$$D_{ij} = \sqrt{b+c} \tag{1}$$

$$DMat = \begin{bmatrix} D_{11} & D_{12} & . & D_{1n} \\ D_{21} & D_{22} & . & D_{2n} \\ . & . & . & . \\ D_{m1} & D_{m2} & . & D_{mn} \end{bmatrix} \tag{2}$$

The decision matrix forms a tree diagram or dendrogram, which depicts similarities between different landslide sites. Based on 37 landslide sites in a pilot database and rating system shown in Table 2, a tree diagram of similarity relationships of all landslide members is illustrated in Fig. 1, in which three groups of landslide hazards emerge. The numerical scores of each landslide site based on hazard groups are summarized in Table 5.

The validity of the landslide hazard rating matrix can be evaluated by using inferential statistics. A good scoring system is expected to give a normal distribution for the numerical scores of all landslide sites in each cluster as well as of all landslide sites in all clusters combined. The Kolmogorov-Smirnov test is a comparison of the empirical and hypothetical distribution functions of hazard scores for each cluster. The null hypothesis is that the numerical scores of all landslide sites are normally distributed. The hypothesis will be rejected when the calculated significance level is less than 0.05. As seen in Table 6, the Kolmogorov-Smirnov test has proven that the distribution of numerical scores of all landslide sites in each cluster as well as in combined clusters is a normal distribution.

The comparisons among the mean of each cluster are made by using ANOVA test. The null hypothesis is that the mean of each individual cluster is equal to the mean of other clusters $(H_o : \mu_{cluster\,1} = \mu_{cluster\,2} = \mu_{cluster\,3})$. If the hypothesis holds, it will result in a relatively small value of MSTr, which is the variance of individual cluster mean compared with the grand mean. The MSE is the variance of each individual hazard score compared to the grand mean. The F can be calculated as the ratio of MSTr and MSE. It is then compared to the critical value of F. The null hypothesis is rejected when the value of F is more than $F_{critical}$. Based on calculation shown in Table 7, the null hypothesis is rejected. The cluster means are not equal.

Table 5. Hazard scores of low, medium, and high cluster

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
LOW	2	3	3	9	81	3	99
	3	3	3	3	9	81	99
	4	3	3	3	27	3	39
	6	9	3	9	9	9	39
	8	81	27	9	9	9	135
	9	27	3	9	9	9	57
	11	3	3	9	81	3	99
	12	27	3	9	81	3	123
	14	27	3	9	81	3	123
	18	3	3	9	81	81	177
	26	3	3	9	81	81	177
	33	81	3	9	9	81	183
	36	3	3	9	81	3	99
	37	3	3	3	9	81	99
MEDIUM	7	27	9	27	9	9	81
	10	81	3	27	9	3	123
	16	81	27	27	27	9	171
	22	81	27	27	27	27	189
	23	81	9	27	9	27	153
	24	81	9	9	27	3	129
	25	81	27	27	27	81	243
	27	81	27	27	3	81	219
	29	81	9	9	3	81	183
	30	81	9	9	3	81	183
	31	81	9	27	9	3	129
	32	81	9	27	9	9	135
HIGH	1	27	81	9	81	27	225
	5	27	81	27	3	81	219
	13	81	81	81	3	27	273
	15	81	81	81	81	3	327
	17	81	81	81	81	9	333
	19	81	81	81	81	81	405
	20	81	81	81	27	81	351
	21	81	81	81	27	9	279
	28	81	81	81	3	3	249
	34	81	81	81	27	81	351
	35	81	81	81	81	27	351

Column heading designation:

(a): Cluster designation

(b): Site number

(c): Movement location/impact

(d): Hazard to traveling public

(e): Decision sight distance

(f): ADT

(g): Maintenance response

(h): Total hazard score

Table 6. Kolmogorov-Smirnov normality test at 95% confidence interval

	Statistic	df	Sig.
Low risk	0.189	14	0.191
Medium risk	0.137	12	0.200
High risk	0.184	11	0.200
All included	0.132	37	0.099

Table 7. ANOVA test of three clusters

Sources of variations	Sum of Squares	df	Mean Square	F	F_{cr}
Treatments (clusters)	244507	2	122253	47	3.3
Error	87572	34	2575		
total	332079	36			

Table 8. t-test of hazard scoring criteria

	Cluster1	Cluster 2		Cluster 3
Hypothesis testing α = 0.05	$H_0 : \mu \le \mu_0$ $H_1 : \mu > \mu_0$ $\mu_0 = 150$	$H_0 : \mu \ge \mu_0$ $H_1 : \mu < \mu_0$ $\mu_0 = 150$	$H_0 : \mu \le \mu_0$ $H_1 : \mu > \mu_0$ $\mu_0 = 250$	$H_0 : \mu \ge \mu_0$ $H_1 : \mu < \mu_0$ $\mu_0 = 250$
Mean	110.20	161.5	161.5	305.73
Std. Dev.	47.04	45.30	45.30	60.20
t	-3.14	0.88	-6.77	3.07
Sig. (2-tailted)/2	0.004	0.200	0.000	0.006
Rejection region for a level α test (α=0.05)	1. $\frac{Sig.(2-tailed)}{2} < \alpha$ *and* 2. $t > 0$	1. $\frac{Sig.(2-tailed)}{2} < \alpha$ *and* 2. $t < 0$	1. $\frac{Sig.(2-tailed)}{2} < \alpha$ *and* 2. $t > 0$	1. $\frac{Sig.(2-tailed)}{2} < \alpha$ *and* 2. $t < 0$
Rejection of H_0	Failed to reject	Failed to reject	Failed to reject	Failed to reject

The t-test is used as a validity test of the hazard scoring criteria where the upper bound and lower bound of the scoring range is tested using the null hypotheses as shown in row 1 of Table 8. The t values and significances are shown in the table. According to the criteria of rejection, the null hypotheses hold. Therefore, the hazard scoring criteria are statistically sufficient for classification of hazard groups.

Summary and Conclusions

A landslide hazard rating system has been developed for Ohio ODOT to evaluate the hazards ranking of all landslides in Ohio highway system so that limited resources could be allocated judiciously to address the needs of various landslide rehabilitation projects. The developed system is based on synthesis of existing systems adopted by other state highway agencies and modified to fit Ohio's particular landslide characteristics and ODOT engineers' experiences. The proposed system shown in Table 2 is capable of identifying three different hazard/risk groups. The validity and reliability of the developed system has been established by using various statistical analysis techniques, such as Kolmogorov-Smirnov test, ANOVA test, and t-test. It is found that the developed rating matrix yields a reliable scoring system, which would allow for ODOT to assess potential hazards of a landslide and to prioritize the ranking of the need for landslide rehabilitation among all landslide sites in the ODOT landslide inventory.

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