Journal of Nepal Geological Society, 2000, Vol. 21, pp. 29-34

Landslide and flood hazard index for mountain roads: an example from the Stura di Demonte Valley, Italy

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ABSTRACT

Road alignments in mountainous areas are subject to heavy damage due to rockslides and floods. The rehabilitation and maintenance works that would be necessary to solve these problems are very costly.

In this paper, the authors present methodology for obtaining, in relatively short time, a sufficiently detailed thematic map in which road alignment is subdivided into segments corresponding to different hazard degrees. As an example for such methodology, a 30 km long stretch of the road alignment in the Stura di Demonte Valley (Piedmont, Northwestern Italy) was chosen. The geomechanical characteristics of rock and soil in the area were obtained at the beginning. Major landslide phenomena (mostly rockfalls and debris flows) damaging the road alignment were located. A qualitative hazard index (H_I) was then calculated by taking into account such factors as affected road length, type and dimensions of the landslide, soil properties, and vegetation.

Major hazards from rivers result from potential floods, which may overflow or erode road structures and destroy bridges and minor crossings. Firstly, the maximum discharge of rivers in the study area was calculated using various hydrological methods. Secondly, river expansion limits were evaluated. Historical data on past flood levels were considered during this process. During the high floods, malfunctioning of brides and other crossing structures can often have very serious consequences. The efficiency level of such structures, therefore was judged, taking their down-flowing section into consideration. For each structure, a comparison between estimated maximum river discharge and allowable discharge level (function of bridge and riverbed characteristics) determines the adequacy index (A_I).

Results of analysis of both flood and landslide hazard were then synthesised in the final hazard map, which shows with simple graphic symbols and an intuitive colour range (in order to allow easy consultation by non-experts), the most important hazard factors, pertinent protection works, and resulting hazard degrees for roads, bridges, and other structures.

INTRODUCTION

Mountain roads very frequently suffer from heavy damages due to landslides and floods (Anselmo 1980). Consequently, they are closed for long periods, as they need frequent repairs and it is often impossible to carry out all of the activities at the same time. On the other hand, the rehabilitation and maintenance costs are also very high. Therefore, it is important to choose where and when to execute such works, and how to rationally utilise the available economic resources.

The proposed methodology takes into account the above constraints. It can produce a reliable hazard map of the road alignment in a relatively short time. As an example of it, the results of the study carried out in a mountainous area of Western Alps (Stura di Demonte Valley, Piedmont, Northwestern Italy; Fig. 1) are presented here (Barisone and Onori 1998).

For this purpose, geological, morphological, and environmental characteristics of the road alignment and its surrounding area are studied. In particular, the study must be extended to a large territory (preferably the whole watershed) around the roads, since the adverse effects can be caused by some remotely situated factors. Particular attention must be paid to the collection of historical data, mainly those concerning with rock instability phenomena and main floods that occurred in the past. These are the only available data useful to evaluate the recurrence intervals of dangers. Their frequencies are important for hazard assessment. These findings are then verified and integrated through extensive field surveys and aerial photograph interpretation.

The data so collected and elaborated may be synthesised to produce several thematic maps at a proper scale. For a good and useful synthesis, the following three types of thematic map are necessary:

- hydrological map of the entire watershed on a scale of 1:50,000 to 1:100,000;
- geological map of the area on a scale of 1:10,000 to 1:25,000, to be chosen taking into consideration the lithological and tectonic complexity; and
- hazard map on a scale of 1:5,000 to 1:10,000, with the detailed information of each road segment.

HAZARD ASSESSMENT

Generally, road alignments in mountainous areas suffer from river undercutting and landslides. A method of hazard assessment for those factors is described below.

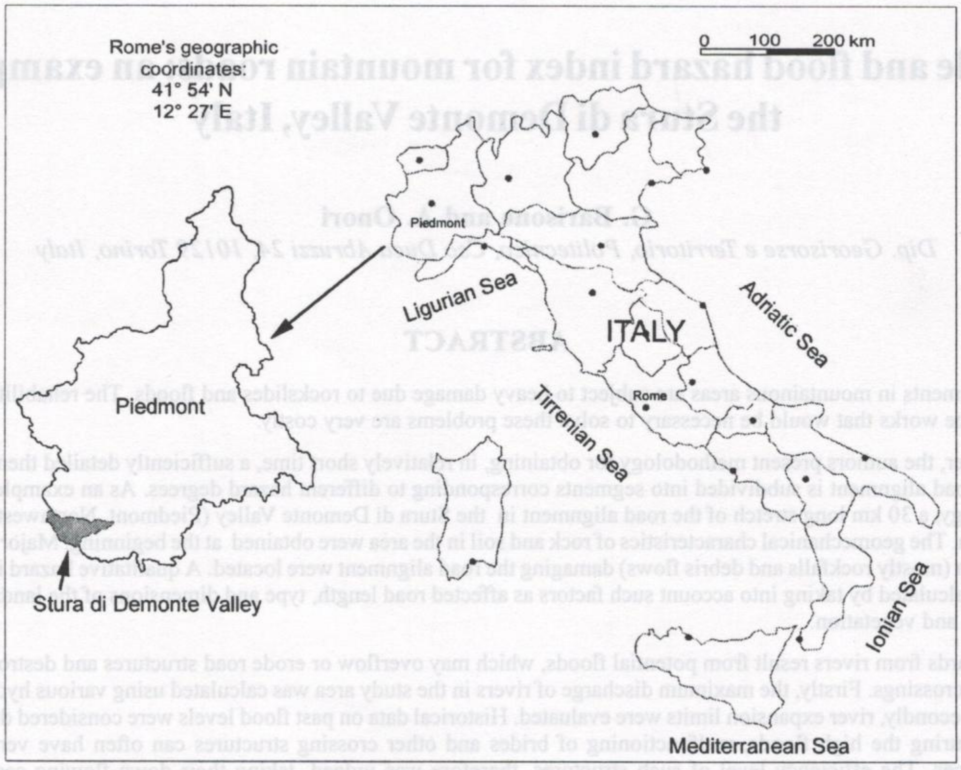


Fig. 1: Location map of the study area

Landslides

The first step of the study is focused on locating and identifying the severe landslide types, and (if possible) their recurrence interval (Barisone and Cotenduca 1998). For each road segment potentially vulnerable to sliding, a hazard index H_i is calculated, taking into account the main factors summarised in Table 1.

Table 1: Main factors considered for hazard index determination for landslides

Factor	Rockfall	Rockslide	Debris flow
Width of slide on uphill side (*d*)	*	*	*
Length of slide(*l*)		*	
Vertical slope height (*h*)	*		
Collapsed mass thickness (*t*)		*	*
Slope angle (*p*)	*	*	*
Slip surface (s)		*	
Debris granulometry (*g*)			*
Maximum block dimensions (*b*)	*		
Vegetation (*v*)	*	*	*

A semi-quantitative evaluation of weighting for each factor is made along the affected road segment by taking into account the number, volume, evolution, and type of the mass movement involved.

As an example of it, a 30 km of road alignment in the Stura di Demonte Valley of Piedmont, Northwestern Italy, was analysed. The main potential failure types involving the stretch were rock fall and debris flow. The Hazard Index H_i related to rock fall was calculated by the empirical formula:

$$H_i = x \cdot y \cdot z$$

where, x = coefficient depending on the d/h ratio; y = coefficient related to the maximum block dimension (b); and z = coefficient depending on the kind of vegetation existing (v).

Parameter p (slope angle) given in Table 1 does not appear in the formula because the foot of vertical slopes is generally made up of soil cover with the slope angle equal to the friction angle of the material (about 40°).

The numerical values of x, y, and z were established by means of back analysis made on a few well known rock falls that occurred in geological and morphological equivalent conditions (Table 2). The relationship between H_i and the

Table 2: Coefficients x, y, and z established from back analysis of rockfalls

Coefficient *x*		Coefficient *y*		Coefficient *z*	
d/h	*x*	Max. blocks volume (m^3)	*y*	Vegetation	*z*
<2	10				
2-5	7	>5	7	Absent, grass	5
6-10	3	2-5	5	Thin wood	3
>10	1	<2	3	Wood	2

corresponding hazard degree for the road alignment is given in Table 3.

Table 3: Correlation between H_i and the hazard degree

H_i	Degree of hazard
>150	High
51-150	Medium
20-50	Low
<20	Null

Floods

In mountainous areas, major hazards from rivers result from potential floods, which may overflow or erode road structures and/or destroy bridges and other minor crossings. When examining the hazard related to river activities, one of the most difficult issues is the evaluation of maximum discharge, the existing formulae being generally suitable only for particular climatic conditions and river basin dimensions. It is therefore advisable to subdivide the rivers in several groups, according to basin dimensions and, if necessary, rock exposure dimensions and lithology.

In the study area, the River Stura di Demonte and its tributaries were divided into the following three categories based on their watershed area:

- more than 100 km² (i.e, the River Stura di Demonte);
- between 10 km² and 100 km²; and
- less than 10 km².

For each group, the maximum discharge was calculated using the most appropriate hydrological methods, which were chosen by comparing results of various formulae with the available experimental discharge data.

The capacity of bridges and other minor crossings to permit the passage of maximum discharge without problems was evaluated. For this purpose, an Adequacy Index A_i for each structure was determined by making a comparison of the calculated maximum river discharge with the allowable discharge level of the structure.

Apparently the allowable discharge calculation needs an accurate measurement of all the geometric characteristics of each bridge and related riverbed section. Moreover, it is useful to consider some other parameters such as the physical condition of structure and its protection measures. An example of the form used for the above study is given in Fig. 2.

The value of A_i was calculated using the following formula:

$$A_i = \frac{k \cdot i^{\frac{1}{2}} \cdot (A_s)^{\frac{2}{3}}}{Q_{\max} \cdot (1+T) \cdot \left(\sum_{i=1}^{n} l_i + 2 \cdot \overline{f}_i \right)^{\frac{2}{3}}}$$

where, k = Strickler's coefficient; i = riverbed gradient; A_s = downstream cross-section area; Q_{max} = estimated maximum flood discharge; T = total load transport coefficient; and l_i = length of each span f_i = clearance between piers.

In the above formula, particularly significant are the total load transport coefficient, estimated maximum discharge, and an attempt to evaluate (reducing the discharge allowed by means of the term under the symbol Σ) the negative effect caused by the presence of piers.

Depending on the values of A_i the minor crossings can be subdivided into several categories, e.g., in the study are there were four classes as shown in Table 4.

Table 4: Correlation between A_i and hydraulic adequacy of crossing structures

A_i	Hydraulic adequacy
>2	Good
1.3-2	Fair
1-1.3	Bad
<1	Very bad

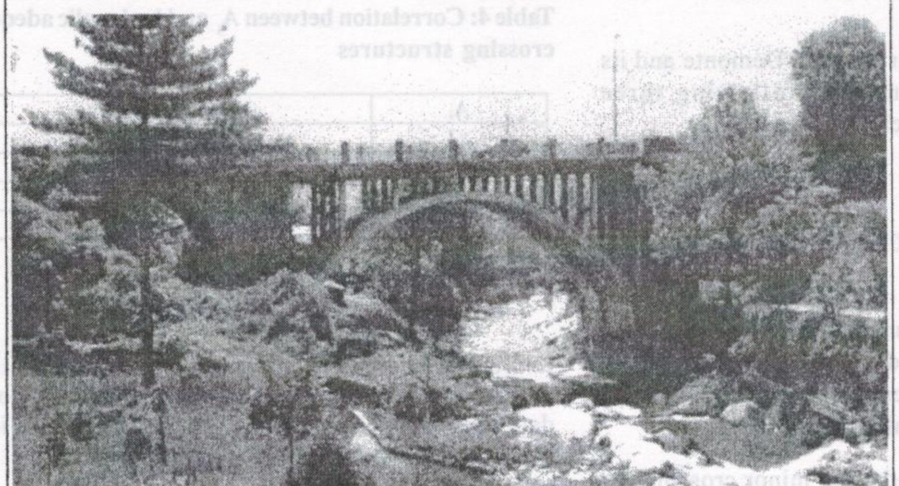
HAZARD MAP

To present the results of such a work, two main goals must be envisaged: to make the large amount of collected data easily available, and to synthesise the results in order to permit a clear and immediate comprehension.

This can be obtained by means of a thematic map on a suitable scale (not less than 1:10,000), where not only all road alignments can be represented with their characteristics (hazard degree, crossing structures, presence of protection structures, etc.), but also the main features of the territory, including hazard factors (areas subject to floods, unstable rock slopes and talus, erosion areas, etc.) and natural protections (vegetation, morphology, etc.).

The hazard map, with a great deal of symbols and colours, is the only way to clearly synthesise such a large amount of information. The sketch map of the study area presented in Fig. 3 is the black and white elaboration of an original coloured sheet. One of the less complicated sheets was chosen to allow a good readability.

Bridge n. 11		
Location	Road	S.S. 21 "della Maddalena", km 16+950
	Locality	Demonte
	River or brook	Torrente Cant
Structure	Number of spans	3
	Typology	Arch
	Construction material	Concrete, stone, bricks
Dimension	Total flowing section [m^2]	370
	Length of a span [m]	10 – 20,6 – 10
	Clearance [m]	5,3 – 10 – 5,8
	Width of piers [m]	5
	Total length [m]	51
	Total width [m]	5,5
Additional data	Physical condition	Good
	Protection structures	River bed protection
	Hydraulic adequacy	Good



Note: during floods, the presence of some minor bridges upstream may interfere with the water flow.

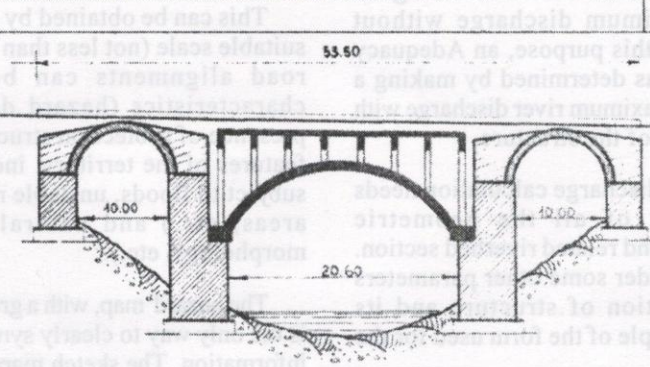


Fig. 2: Bridge characteristics form

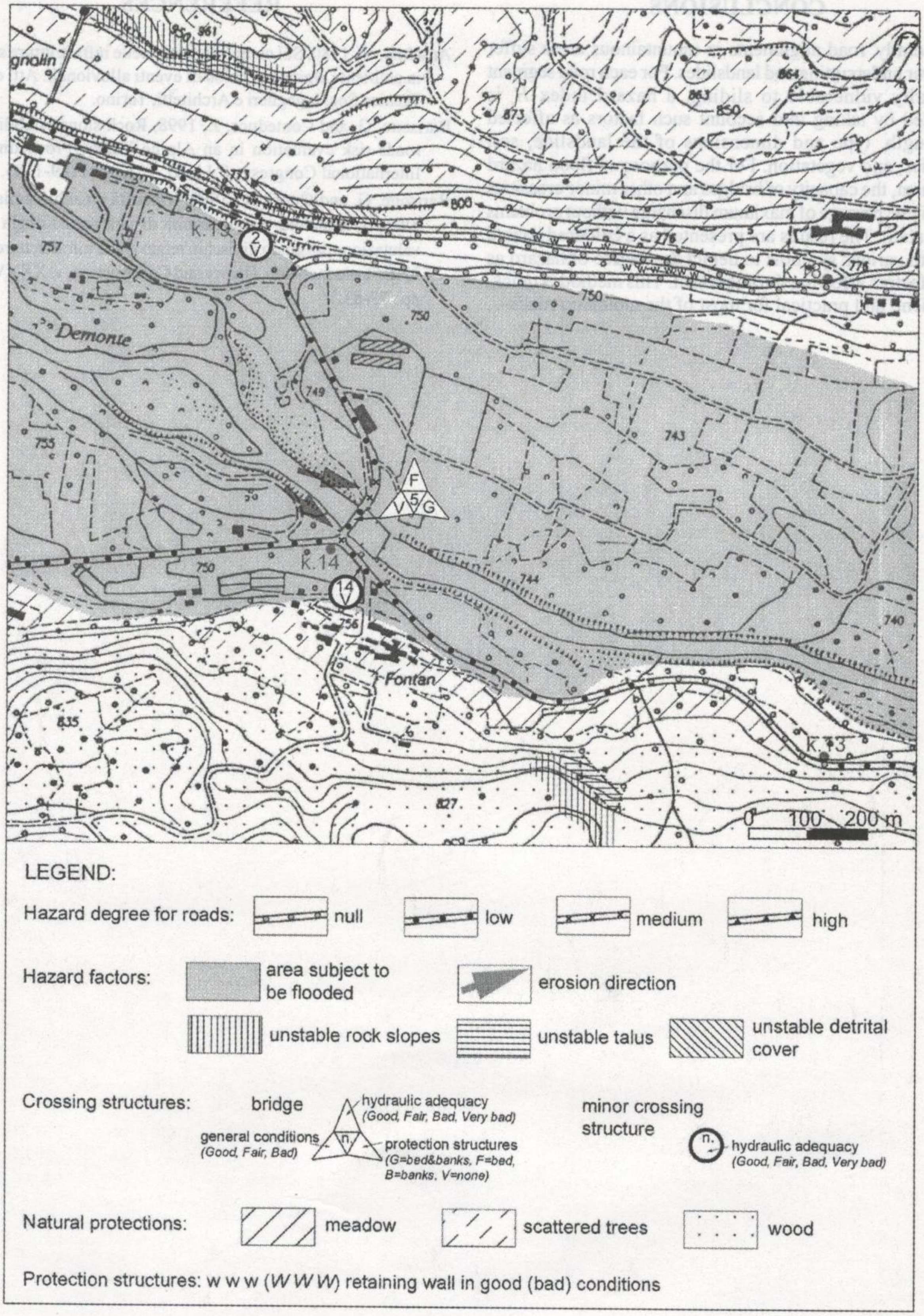


Fig. 3: Sketch of a road hazard map

CONCLUSIONS

Generally, road alignments in mountainous areas suffer from river undercutting and landslides. For each road segment potentially vulnerable to sliding, a hazard index H_i is calculated by taking into account such factors as affected road length, type and dimensions of the landslide, soil properties, and vegetation. For the purpose of flood hazard assessment, the capacity of bridges and other minor crossings to permit the passage of maximum discharge without problems is evaluated. The results are presented as a coloured hazard map with various symbols to depict the degree of hazard as well as factors affecting the alignment. This method is quick, convenient, and practical for most of the mountain roads.

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