BULLETIN of the International Association of ENGINEERING GEOLOGY de l'Association Internationale de GÉOLOGIE DE L'INGÉNIEUR Paris – No 52 – Octobre 1995

A SUGGESTED METHOD FOR DESCRIBING THE RATE OF MOVEMENT OF A LANDSLIDE

PROPOSITION D'UNE MÉTHODE POUR QUALIFIER LA VITESSE D'UN MOUVEMENT DE TERRAIN

INTERNATIONAL UNION OF GEOLOGICAL SCIENCES WORKING GROUP ON LANDSLIDES

Abstract

The rate of movement of a landslide can range from extremely slow, less than 16 mm/year or 0.5×10^{-6} mm/second, to extremely rapid, over 5 m/second. Five intermediate classes cover two orders of magnitude of velocity each. The velocity of a landslide can be correlated with the damage it may cause.

Résumé

La vitesse d'un mouvement de terrain peut varier entre une valeur extrêmement lente, inférieure à 16 mm/an, soit $0.5 \cdot 10^{-6}$ mm/s, et une valeur extrêmement rapide, supérieure à 5 m/s. Cinq classes intermédiaires de vitesse sont proposées, couvrant chacune deux puissances de 10. On peut tenter de corréler la vitesse d'un mouvement de terrain aux dommages causés par celui-ci.

Introduction

The International Union of Geological Sciences Working Group on Landslides is a continuation of the International Geotechnical Societies' Unesco Working Party on World Landslide Inventory (WP/WLI). It was formed from the IAEG's Commission on Landslides and Other Mass Movements, the ISSMFE's Technical Committee on landslides, and nominees of National Groups of the International Society for Rock Mechanics. As a contribution to the International Decade for Natural Disaster Reduction (1990-2000), the Working Group is assisting the establishment of a World Landslide Inventory by suggesting standard terminology for describing landslides. The Working Group has suggested a method for reporting a landslide (WP/WLI, 1990), for preparing a landslide summary (WP/WLI, 1991), and for describing the activity of a landslide (WP/WLI, 1993a). These are summarized in the Multilingual Landslide Glossary (WP/WLI, 1993b). Our working definition of a landslide is "the movement of mass of rock, earth or debris down a slope" (Cruden, 1991).

The Working Group has set up Committees to extend the scope of the Landslide Report to the rates of movement of landslides, their causes (WP/WLI, 1994), their geology, and the damage landslides may cause. The suggestions from the Committee on Rate of Movement define a simple velocity scale and will be used to supplement the Landslide Report. The Working Group welcomes carefully documened proposals for additions or amendments to this (and other) Suggested Methods. They should be addressed to the chairman of the Working Group (currently Dr. D.M. Cruden, Department of Civil Engineering, University of Alberta, Edmonton, Alberta, Canada, T6G 2G7).

The Suggested Method first reviews methods of describing the velocities of landslides, then discusses the Working Group's views. The Suggested Method is summarized in Table 1.

Review

The rate of movement scale presented by Varnes (1978) in part of the chart of types of slope movement (Fig. 2:1 u) is unchanged from Varnes (1958) with the exception of the addition of equivalent SI units; these range from 3 metres/second to 0.06 metres/year. Varnes (1958) did not discuss his selection of the seven divisions of the scale, which was given in units ranging from feet/second to feet/5 years; this organization probably represented a codification of informal practive in the USA at the time. Nemcock *et al.* (1972) suggested a four-fold division of a similar range of velocities.

The Working Group proposes to retain the seven divisions included in the Varnes scale. It is difficult though to evaluate on a single scale the movement of extremely slow landslides which may move for hundreds of years and extremely fast rock slides which may last a few minutes. However, we suggest that the limits be adjusted so that all the divisions of the velocity scale are multiples of 100 (0.5 and 50 mm/s, for instance – see Table 1). This can be achieved by slightly increasing the lower limit of upper class of Varnes scale from 60 to 16 mm/year. These two limits, including the five intermediate divisions, span ten orders of magnitude in the velocity scale.

Morgenstern (1985) drew an analogy between the divisions of the Varnes scale and the modified Mercalli scale of earthquake intensity. He pointed out that the effects of a landslide can be sorted into six categories corresponding approximately to the six fastest movement ranges of the Varnes scale. The Working Group has added a seventh category frequently met in built-up areas affected by extremely slow movements to correspond with the divisions of the velocity scale (see Table 1).

Discussion

The slope-movement literature lacks a unified scale of degree of destruction, comparable to the Mercalli scale of earthquake intensity. The Mercalli scale is based on descriptions of local effects of an earthquake; degrees of damage can be evaluated by investigating a house or a section of a street. On the other hand, the earthquake magnitude can be correlated with the total energy release of the event. Both local damage and the area affected are related to the magnitude of the earthquake, although the foundation and structural systems of the buildings and the response of the ground also play an important part in the magnitude of the damage.

The situation is different for landslides. Very small, rapid, debris avalanches are known to have caused total destruction and loss of lives locally. On the other hand, a large slope movement of moderate velocity may have much less serious effects because it can be avoided if it has been detected previosuly, or the structures affected can be evacuated and rebuilt or protected by physical control works. This suggests that a measure of landslide risk requires an understanding of both the volume affected and the probable maximum velocity; the product of these two parameters is approximately proportional to the gross power release of the landslide.

Varnes *et al.* (1984) drew attention to the UNDRO (now the United Nations Department of Humanitarian Affairs – UNDHA) terminology in which the specific risk, R_s, the expected degree of loss due to landsliding or other natural phenomena, can be estimated as the product $H \times V$. The hazard, H, is the probability of occurrence of the phenomena within a given area; the vulnerability, V, is the expected degree of loss of elements at risk, namely population, properties and economic activities in the given area. The vulnerability ranges from 0 to 1. The landslide risk, is then obtained by multiplying R_s by the value of exposed objects. In this terminology, the velocity of the landslide might be correlated with vulnerability and the hazard with landslide volume.

A third fundamental parameter, which is difficult to quantify, is the internal distortion of the displaced mass. Structures and buildings on the mass would be damaged in proportion to the internal distortion or differential velocity affecting their foundations (Gabus *et al.*, 1988. Noverraz and Bonnard, 1990). For example, the Lugnez landslide in Switzerland (Huder, 1976) has an area of 25 km^2 (total volume: 4×10^9m^3), moving steadily down a 15° slope at velocities of up to 0.37 m/year. The movements have been observed by surveying since 1887. Yet, there are six large villages on the slope, with 300-year-old stone houses and 15th century churches with bell towers. None of these structures have suffered significant damage when displaced over centuries because the sliding ground on which they are founded is locally moving without distortion. Thus, damage will also depend on the type of landslide, and each type may require separate consideration; a numerical parameter similar to vulnerability could take this distortion phenomenon into account.

Table 1 : Velocity Classes

OLD CLASSES (Varnes, 1978)		NEW CLASSES (WP/WLI, 1994)				
Velocity	Value in mm/sec	Vel Class	Description of velocity	Examples (Table 2)	Velocity limits	Value in mm/sec
		7	Extremely rapid	1-8 [2]		
3 m/sec	$3 \cdot 10^3$	------	-------------------	-----------------	5 m/sec	$5 \cdot 10^3$
600 [1]		6	Very rapid	8 [2]-9	*100* [1]	
0.3 m/min	5	------	-------------------	-----------------	3 m/min	50
288		5	Rapid	10-11	*100*	
1.5 m/day	$17 \cdot 10^{-3}$	------	------	-----------------	1.8 m/hour	0.5
30		4	Moderate	12-14	*100*	
1.5 m/month	$0.6 \cdot 10^{-3}$	------	-------------------	-----------------	13 m/month	$5 \cdot 10^{-3}$
12		3	Slow	15-17	*100*	
1.5 m/year	$48 \cdot 10^{-6}$	------	-------------------	-----------------	1.6 m/year	$50 \cdot 10^{-6}$
25		2	Very slow	18-22	*100*	
0.06 m/year	$1.9 \cdot 10^{-6}$	------	-------------------	-----------------	16 mm/year	$0.5 \cdot 10^{-6}$
		1	Extremely slow	23-24		

[1] Multiplication factor between lower and higher velocity limit
[2] Two estimated values are available (see Table 2)

Proposal

Velocity alone is a parameter whose destructive significance requires definition. Some typical case histories in which the effects of a landslide on humans and their activities have been well described and for which maximum velocities are also known are listed in Table 2. These cases have been sorted into seven categories, according to the **maximum recorded velocity during an exceptional behaviour phase.** The seven classes of velocity given in Table 1 thus correspond to the following situations and damage, provided that exposed structures do exist :

7. Catastrophe of major violence. Exposed buildings totally destroyed and population killed by impact of displaced material, or by disaggregation of the displaced mass.

6. Some lives lost, because the landslide velocity is too great to permit all persons to escape. Major destruction.

5. Escape evacuation possible. Structures, possessions and equipment destroyed by the displaced mass.

4. Insensitive structures can be maintained if they are located a short distance in front of the toe of the displaced mass ; structures located on the displaced mass are extensively damaged.

3. Roads and insensitive structures can be maintained with frequent and heavy maintenance work, if the movement does not last too long and if differential movements at the margins of the landslide are distributed across a wide zone.

2. Some permanent structures undamaged or, if they are cracked by the movement, they can be repaired.

1. No damage to structures built with precautions.

Table 1 shows a correspondence between the vulnerability classes as defined above and the selected landslide velocity scale. A major limit appears to lie between very rapid and extremely rapid movement, which approximates the speed of a person running (5 m/sec) and clearly separates rock fall from most of the flow phenomena. Another important boundary is between the slow and very slow classes (1.6 m/year), below which some structures on the landslide are undamaged. Finally, the upper limit of class 1 (extremely slow movement) is the velocity (16 mm/year) below which most types of buildings will not be damaged if their foundations are adapted to movements, to avoid some cracking of walls.

Final comments

We note that the proper determination of the peak velocity of any given landslide, considering the spatial and temporal variation of movements, is a very difficult task if the right monitoring equipment is not available on the site at the right moment, or if its operation is affected by the conditions in which the catastrophic phase of the movement occurs, by night, by dust, by fear, and so forth. Therefore, it is not necessary, considering the qualitative aim of this velocity scale, to focus on the proposed limits of the scale as if they were rigid values.

This classification of rates of movement is obviously schematic, as peak velocity alone may not give a sufficient description of the related event (eg. at the margin of a slide). It does not include a parameter to express the ratio between the peak velocity used in the vulnerability scale and the long-term average velocity that is

Table 2 : Examples of landslide maximum velocity and damage

1. **Elm,** Heim (1932), 70 m/sec, 115 lives (class 7).
2. **Goldau,** Heim (1932), 70 m/sec, 457 lives (class 7).
3. **Jupille,** Bishop (1973), 31 m/sec, 11 lives, houses destroyed (class 7).
4. **Frank,** McConnell and Brock (1904); 28 m/sec, 70 lives (class 7).
5. **Vajont,** Mueller (1964), 25 m/sec, 1900 lives lost by indirect damage (classe 7).
6. **Ikuta,** Engineering News-Record (1971), 18 m/sec, 15 lives, equipment destroyed (class 7).
7. **St-Jean Vianney,** Tavenas *et al.* (1971), 7 m/sec, 14 lives, structures destroyed (lower limit of class 7).
8. **Aberfan,** Bishop (1973), 4.5 m/sec to 13.5 m/sec, according to different witnesses, 144 lives, some buildings damaged (lower limit of class 7 or upper limit of class 6).
9. **Jitsukiyama,** Fukuoka (1989), 6 m/min for minutes ; some persons could not be evacuated from an old people's home ; retaining walls, houses, roads destroyed (lower limit of class 6).
10. **Converney** (active zone of February 1990), Noverraz *et al.* (1991), 3 m/min, no one hurt, a house destroyed, four houses seriously damaged by the sliding mass (upper limit of class 5).
11. **Panama Canal,** Cross (1924), 1 m/minute, equipment trapped, people escaped (class 5).
12. **Handlova,** Zaruba and Mencl (1982), 6 m/day, 150 houses destroyed, complete evacuation (class 4).
13. **La Chenaula,** Noverraz and Bonnard (1992), 20 cm/hour, road destroyed and riverbed at the toe of the landslide displaced (class 4).
14. **Rainbow Avenue,** (Los Angeles), Scott (1978), 50 cm/day, houses partially destroyed (lower limit of class 4).
15. **Schuders,** Huder (1976), 10 m/year, road maintained with difficulty (class 3).
16. **Wind Mountain,** Palmer (1977), 10 m/year, road and railway required frequent maintenance, buildings adjusted periodically (class 3).
17. **La Frasse,** Bonnard (1983), 10 cm/day during 2 weeks and 3 m/year during 2 years, lower road maintained with difficulty, chalets cracked but still habitable (class 3).
18. **La Frasse,** Noverraz and Bonnard (1990), in deep zones, several slightly cracked or distorted houses, 15-30 cm/year (class 2).
19. **Lugnez,** Huder (1976), 0.37 m/year, six villages on slope undisturbed (class 2).
20. **Little Smoky,** Thomson and Hayley (1975), 0.15 m/year, bridge protected by a slip joint (class 2).
21. **Klosters,** Haefeli (1965), 0.02 m/year, tunnel maintained, bridge protected by a slip joint (lower limit of class 2).
22. **Ft. Peck Spillway,** Wilson (1970), 0.02 m/year, mouvements unacceptable, slope to be flattened (lower limit of class 2).
23. **Arveyes,** Gabus *et al.* (1988), 16 mm/year for one month, village mostly in good state, some houses slighlty cracked (upper limit of class 1).
24. **Converney** (main landslide), Noverraz *et al.* (1991), < 10 mm/year, hundreds of houses in good state.

easier to determine for very slow landslides, on the basis of their morphological features. This ratio is important because high values express an element of surprise for the population involved. Furthermore, the determination of the peak velocity in classes 5 and lower greatly depends on the time during which the movements were observed and on the eventuality of recording an exceptional acceleration. Further discussion will improve this first proposal. Meanwhile, to promote simple and meaningful information on landslide velocity in the World Landslide Inventory, the proposed scale is considered a practical method of including velocity data in a Landslide Report.

Acknowledgements

The draft of this suggested method was prepared by the Committee on Rate of Movement, chaired by Ch. Bonnard, with members DM. Cruden, H.H. Einstein, S. Novosad, G. Salt, R.L. Schuster, Z.G. Ter-Martirosian and D.J. Varnes. We are grateful for interesting suggestions by O. Hungr, N. Morgenstern, G. Ter-Stepanian and R. Fell. We are grateful to UNESCO'S Earth Science Division for funding travel of some members to meetings to discuss this suggested method.

References

BISHOP A.W., 1973 : Stability of tips and spoil heaps. Quarterly Journal of Engineering Geology. **6** : 335-376.

BONNARD Ch., 1983 : Determination of slow landslide activity by multidisciplinary measurement techniques. Proceedings International Symposium on Field Measurements in Geomechanics. Zurich, **1** : 619-638.

CROSS W., 1924 : Historical sketch of the landslides of the Gaillard cut. United States National Academy of Science Memoir. **18** : 22-43.

CRUDEN D.M., 1991 : A simple definition of a landslide. Bulletin International Association of Engineering Geology. **43** : 27-29.

ENGINEERING NEWS-RECORD, 1971 : Contrived landslide kills 15 in Japan. **187** : 18.

FUKUOKA M., 1989 : Detection, exploration and monitoring for Jitsukiyama Landslide in Japan. Proceedings 1st South American Symposium on Landslides. Paipa, Colombia, **1** : 1-35.

GABUS J.H., BONNARD Ch., NOVERRAZ F. et PARRIAUX A., 1988 : Arveyes, un glissement, une tentative de correction. Proceedings 5th International Symposium on Landslides. Lausanne, **2** : 911-914.

HAEFELI R., 1965 : Creep and progressive failure in snow, soil, rock and ice. Proceedings 6th International Conference on Soil Mechanics and Foundation Engineering. Montreal, **3** : 134-148.

HEIM A., 1932 : Bergsturz and Menschenleben. Fretz und Wasmuth, Zurich, 218 p; [Also in English translation, Skermer, 1989].

HUDER J., 1976 : Creep in Bundner Schist. Laurits Bjerrum Memorial Volume. Norwegian Geotechnical Institute, Oslo, pp. 125-153.

McCONNELL R.G. and BROCK R.W., 1904 : Report on the great landslide at Frank. Alberta, Department of the Interior, Annual Report for 1903. Ottawa, Part 8, 17 p.

MORGENSTERN N.R., 1985 : Geotechnical aspects of environmental control. Proceedings 11th International Conference on Soil Mechanics and Foundation Engineering. San Francisco, **1** : 155-185.

MUELLER L., 1964 : The rock slide in the Vajont Valley. Rock Mechanics and Engineering Geology. **2** : 1489-1512.

NEMCOK A., PASEK J. and RYBAR J., 1972 : Classification of landslides and other mass movements. Rock Mechanics **4** : 71-78.

NOVERRAZ F. and BONNARD Ch., 1990 : Technical note on the visit of La Frasse Landslide. Proceedings 5th International Symposium on Landslides. Lausanne, **3** : 1549-1554.

NOVERRAZ F. and BONNARD Ch., 1992 : Le glissement rapide de la Chenaula. Proceedings International Symposium INTERPRAEVENT. Berne, **2** : 65-76.

NOVERRAZ F., BONNARD Ch. and GIRAUD A., 1991 : Environmental impact of a large landslide near Lausanne, Switzerland. Proceedings International Conference on Slope Stability Engineering. Institution of Civil Engineers, Isle of Wight, pp. 101-106.

PALMER L., 1977 : Large rockslides of the Columbia River gorge, Oregon and Washington. Reviews in Engineering Geology, Geological Society of America **3** : 69-83.

SCOTT R.F., 1978 : Incremental movement of a rockslide, in B. Voight, Rockslides and Avalanches **1** : 659-668, Elsevier, Amsterdam.

SKERMER N., 1989 : Landslides and human lives, Bitech, Vancouver, 195 p.

TAVENAS F., CHAGNON J.Y. and LAROCHELLE P., 1971 : The Saint-Jean Vianney landslide : Observations and eyewitness accounts. Canadian Geotechnical Journal **8** : 463-478.

THOMSON S. and HAYLEY D.W., 1975 : The Little Smoky Landslide, Canadian Geotechnical Journal, **12** : 379-392.

VARNES D.J., 1958 : Landslide types and processes, in Landslides and Engineering Practice (Eckel, E.B., ed.). Highway Research Board, National Academy of Sciences, Washington, D.C., Special Report, **29** : 20-47.

VARNES D.J., 1978 : Slope Movement Types and Processes, in Landslides : Analysis and Control. (Schuster R.L. and Krizek R.J., eds.) Transportation Research Board, National Academy of Sciences, Washington, D.C., Special Report **176** : 11-33.

VARNES D.J. *et al.*, 1984 : Landslide Hazard Zonation : a review of principles and practice. UNESCO, Paris, 63 p.

WILSON S.D., 1970 : Observational data on ground movements related to slope instability. American Society of Civil Engineers, Journal Soil Mechanics and Foundations Division. **96** : 1521-1544.

WP/WLI, 1990 : A suggested method for reporting a landslide. Bulletin International Association of Engineering Geology. **41** : 5-12.

WP/WLI, 1991 : A suggested method for a landslide summary. Bulletin International Association of Engineering Geology. **43** : 101-110.

WP/WLI, 1993a : A suggested method for describing the activity of a landslide. Bulletin International Association of Engineering Geology. **47** : 53-57.

WP/WLI, 1993b : Multilingual Landslide Glossary. Bitech, Richmond, British Columbia.

WP/WLI, 1994 : A suggested method for reporting landslide causes. Bulletin International Association of Engineering Geology. **50** : 71-74.

ZARUBA Q. and MENCL V., 1982 : Landslides and Their Control. Elsevier, Amsterdam, 324 p.