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CONSTRUCTION SCHEME OF A SLOPE STABILITY MAP BY AIR PHOTOGRAPHS

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The purpose of this publication is to enable the drawing up of a map on the stability of the slopes by means of the study of air photographs, which is obviously completed by surveys on the field and by eventual laboratory tests. A methodology has been followed which is very simple in its general definition but in the meantime is very complete and well-defined in all its details.

The technique of air photographs has been chosen as the main operating instrument since this method is the only one which enables to have an overall sight, namely a global and complete sight of the area concerned; by using an other type of operating method it would be impossible to obtain such an overall sight, even after long periods of time spent on the interested area. Furthermore the air photographs technique enables the collection of data relevant to all those areas which it would be impossible to observe closely because of their inaccessibility; and finally by adopting this technique it is possible to reduce the working-stages and as a result of this also the costs for the accomplishment of the work.

The drawing up of a map of the stability of the slopes in a determinate area must be headed by study of all those factors which may directly or indirectly exert an influence on the stability of a slope. The factors which may be taken into consideration are numerous; from this last fact arises the necessity to make a selection grounded on their importance and naturally on the possibility to survey them through the air photographs. The selected factors are: the lithology, the inclination of the slopes, the type and the degree of erosion of the slopes and their exposition particularly on the mountain areas, the lying of the layers (strata attitude), the vegetable cover, the climatic conditions and the seismic data.

The study of all those factors leads to the determination of the potential stability or instability of the slopes. At this stage it is necessary to take into consideration another factor which alone is able to modify the results obtained with the analytic study of the above-listed parameters: namely, the human activity. In fact the man can compromise the stability of a slope with inconsiderate and wrong-accomplished works; he can cause the instability of a slope which on the contrary would be stable-natured; and in the meantime man can reclaim and give stability with adequate works to a slope which is unstable-natured.

The analytic study of all those factors or parameters leads to the drawing up of thematic maps which represent some intermediate stages of the work, such as for example the lithologic map, that of the inclination of the slopes, a simplified geomorphological map and so on. The crossing and the overlap of these thematic maps enable the obtaining of the final stability map; besides some documents, which have an indisputable validity and importance, have been obtained without any further waste of time and following the usual system to work.

1. Lithologic map

The preparation of this map requires the following operation stages. Bibliographic research, interpretation-code or interpretation-key, aerial photograph interpretation, scoutings on the field, eventual laboratory tests.

Through these stages it is possible to make a classification of the rocks, which is grounded on a certain number of classes obtained by taking into consideration the lithologic nature, the mechanical characteristics (compactness, porosity, angle of internal friction, cohesion) and the eventual sedimentary (stratification) and tectonic structures.

The lithologic classification is illustrated in table I.

Table I. Correlation among lithology, dip of slopes and strata attitude, for the construction of the potential slope stability map.
Instability classes: 0 - 4, maximum; 5 - 8 strong; 9 - 12 average; 13 - 16 low; 17 - 23 good stability.

Relation between strata and slope	*Dip of slopes* (> 50 % = − 2; 50 - 35 % = − 1; 35 - 20 % = 0; 20 - 10 % = + 1; < 10 % = + 2)	*Lithological features* 1 *Chaotic rocks (Argille scagliose)*	2 *Pseudocohesive rocks including strata of cohesive rocks*	3 *Stratified or not stratified cohesive rocks laying on semicohesive rocks*	4 *Not stratified pseudocohesive rocks (Clay, silt)*	5 *Unconsolidated material (Sand, gravel, detritus)*	6 *Semicohesive rocks (Friable or loosely consolidated sanstones)*	7 *Alternation between cohesive and pseudocohesive rocks, both stratified*	8 *Cohesive rocks with thin strata of semicohesive rocks interbedded*	9 *Well stratified cohesive rocks (Limestones, sandstones, gneiss)*	10 *Cohesive, massive rocks (Limestones, dolomites, granites)*
1. Chaotic rocks, without structures	> 50 %	0	1	2	3	4	5	6	7	8	
	50 - 35 %	1	2	3	4	5	6	7	8	9	
	35 - 20 %	2	3	4	5	6	7	8	9	10	
	20 - 10 %	3	4	5	6	7	8	9	10	11	
	< 10 %	4	5	6	7	8	9	10	11	12	
2. Strongly jointed or disturbed and sometime overturned bed-rocks (strata)	> 50 %		2	3	4	5	6	7	8	9	
	50 - 35 %		3	4	5	6	7	8	9	10	
	35 - 20 %		4	5	6	7	8	9	10	11	
	20 - 10 %		5	6	7	8	9	10	11	12	
	< 10 %		6	7	8	9	10	11	12	13	
3. Dipslope strata (from 30° to 60°) Transverse (traverslope) strata ($\varphi = 30° - 60°, \alpha = 0° - 10°$)	> 50 %		3	4	5	6	7	8	9	10	
	50 - 35 %		4	5	6	7	8	9	10	11	
	35 - 20 %		5	6	7	8	9	10	11	12	
	20 - 10 %		6	7	8	9	10	11	12	13	
	< 10 %		7	8	9	10	11	12	13	14	
4. Faceslope strata with dipslope fracture-system	> 50 %		4	5	6	7	8	9	10	11	
	50 - 35 %		5	6	7	8	9	10	11	12	
	35 - 20 %		6	7	8	9	10	11	12	13	
	20 - 10 %		7	8	9	10	11	12	13	14	
	< 10 %		8	9	10	11	12	13	14	15	

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5. Dipslope strata (from 5° to 30°)	> 50 %		5	6	7	8	9	10	11	12	
Transverse (traverslope) strata	50 - 35 %		6	7	8	9	10	11	12	13	
($\varphi = 5° - 30°$. $\alpha = 0° - 10°$)	35 - 20 %		7	8	9	10	11	12	13	14	
	20 - 10 %		8	9	10	11	12	13	14	15	
	< 10 %		9	10	11	12	13	14	15	16	
6. Transverse (traverslope) strata	> 50 %		6	7	8	9	10	11	12	13	
($\varphi = 30° - 60°$; $\alpha = 10° - 60°$)	50 - 35 %		7	8	9	10	11	12	13	14	
	35 - 20 %		8	9	10	11	12	13	14	15	
	20 - 10 %		9	10	11	12	13	14	15	16	
	< 10 %		10	11	12	13	14	15	16	17	
7. Transverse (traverslope) strata	> 50 %		7	8	9	10	11	12	13	14	
($\varphi = 5° - 30°$, $\alpha = 10° - 60°$)	50 - 35 %		8	9	10	11	12	13	14	15	
	35 - 20 %		9	10	11	12	13	14	15	16	
	20 - 10 %		10	11	12	13	14	15	16	17	
	< 10 %		11	12	13	14	15	16	17	18	
8. Vertical strata (from 85° to 90°).	> 50 %		8	9	10	11	12	13	14	15	
	50 - 35 %		9	10	11	12	13	14	15	16	
	35 - 20 %		10	11	12	13	14	15	16	17	
	20 - 10 %		11	12	13	14	15	16	17	18	
	< 10 %		12	13	14	15	16	17	18	19	

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Relation between strata and slope	Dip of slopes > 50 % = − 2 50 - 35 % = − 1 35 - 20 % = 0 20 - 10 % = + 1 < 10 % = + 2	Lithological features 1 *Chaotic rocks (Argille scagliose)*	2 *Pseudocohesive rocks including strata of cohesive rocks*	3 *Stratified or not stratified cohesive rocks laying on semicohesive rocks*	4 *Not stratified pseudocohesive rocks (Clay, silt)*	5 *Unconsolidated material (Sand, gravel, detritus)*	6 *Semicohesive rocks (Friable or loosely consolidated sanstones)*	7 *Alternation between cohesive and pseudocohesive rocks, both stratified*	8 *Cohesive rocks with thin strata of semicohesive rocks interbedded*	9 *Well stratified cohesive rocks (Limestones, sandstones, gneiss)*	10 *Cohesive, massive rocks (Limestones, dolomites, granites)*
9. Dipslope strata (from 60° to 85°) Transverse (traverslope) strata ($\varphi = 30° - 60°$, $\alpha = 60° - 90°$)	> 50 %		9	10	11	12	13	14	15	16	
	50 - 35 %		10	11	12	13	14	15	16	17	
	35 - 20 %		11	12	13	14	15	16	17	18	
	20 - 10 %		12	13	14	15	16	17	18	19	
	< 10 %		13	14	15	16	17	18	19	20	
10. Horizontal strata (from 0° to 5°) Transverse (traverslope) strata ($\varphi = 5° - 30°$, $\alpha = 60° - 90°$)	> 50 %		10	11	12	13	14	15	16	17	
	50 - 35 %		11	12	13	14	15	16	17	18	
	35 - 20 %		12	13	14	15	16	17	18	19	
	20 - 10 %		13	14	15	16	17	18	19	20	
	< 10 %		14	15	16	17	18	19	20	21	
11. Faceslope strata, massive rocks and alluvial terraces	> 50 %		11	12	13	14	15	16	17	18	19
	50 - 35 %		12	13	14	15	16	17	18	19	20
	35 - 20 %		13	14	15	16	17	18	19	20	21
	20 - 10 %		14	15	16	17	18	19	20	21	22
	< 10 %		15	16	17	18	19	20	21	22	23

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2. Map of the inclination of the slopes

This map is drawn up by utilizing pre-existing topographic maps and by reconstructing the course of the slopes by means of the contour lines.

Under particular circumstances, such as the accurate control of limited areas which are particularly interesting or the control of topographic maps not enoughly revised and valid from the altimetric view-point, the inclination of the slopes may be valued directly on the air photographs by following for example, the ZORN-ITC method which gives results corrected from the deformations due to the stereoscopic exaggeration and approximated of the order of the degree.

In order to select the classes of the inclination of the slopes see table I.

3. Map of the strata attitude

At the beginning it is necessary to separate the layers with normal lying (upright layers) from those with overturned lying (overturned layers). From the connection between strike direction-inclination of the layers and the incline of the slopes it is possible to classify the following types of lying: horizontal layers, faceslope layers, traverslope layers, dipslope layers more and less inclinated than the slope, and vertical layers.

Different from all other types of layers are those layers which are strongly pleated and fractured: they are usually called: "layers with chaotic lying".

As far as the traverslope layers are concerned, it is very important to determine the connection existing between ϕ (actual dipping of the layer) and α (angle between strike direction and ridge) as showed in figure 1.

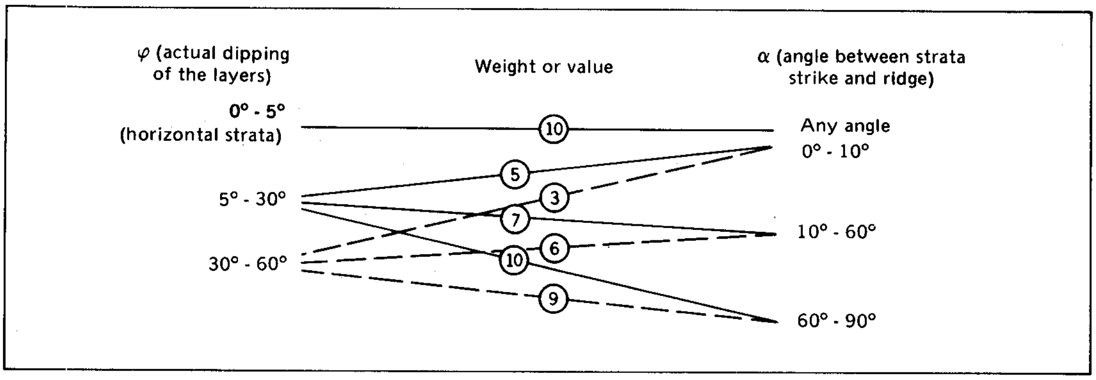

Figure 1

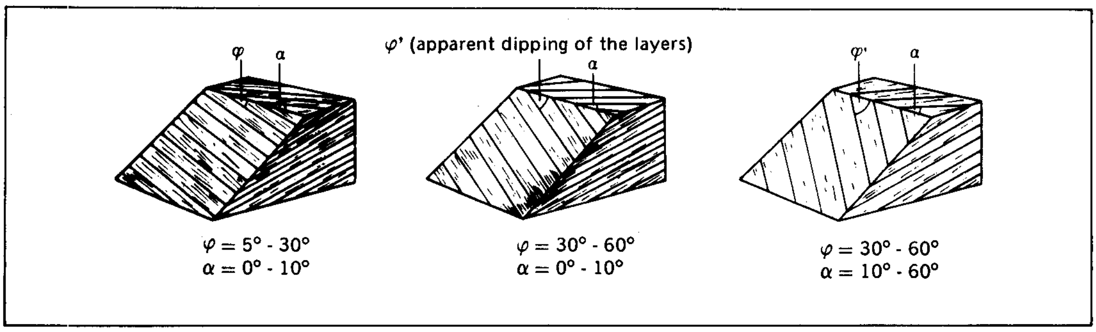

Figure 2

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4. Map of the actual land-use

The purpose of this map is to emphasize the influence of the vegetation on the erosion degree of the slopes and on the consequent hydrogeological attitude of the area as a result of the delimitation of the wood lands, of the cultivated areas, of the meadow-pasture areas, of the denuded areas and of those areas where rock-outcrops occur; in the meantime this map lays emphasis on man's works on the land and then on the influence that those works may have directly or indirectly had on the stability of the slopes. Some examples of human interventions on the land are represented by the mining-works, the lottings, the denudations for public and private works, and so on.

Table II shows the classification of the real land-use in connection with the erodibility of the slopes.

5. Geomorphologic map

Through the aerial photographs interpretation it is possible to obtain the fundamental morphologic characteristics of the area which is examined, thus drawing up a map by following the methodology proposed by the I.T.C. of Enschede for the drawing up of the morpho-conservation map. The fundamental symbology is that shown in figure 3.

This geomorphologic map has a double importance: it permits to control the aerial photointerpretation made till this stage of the work; it enables to emphasize an eventual narrow instability zone inside a stability area. For example in an alluvial terrace we can find a fluvial escarpment subject to lateral river erosion; in every case it represents a well limited phenomenon due to well known and definite causes.

Table II. Land-use classification.

Classification	*Impedance*	*Weight*
Degraded and denuded areas • Simple and arboreal sowables • Areas subject to mining activities • Denudations in slopes with great inclinations.	Nothing	− 2
Waste and barren lands • Bushy areas, or lands with a short arboreal cover • Specialized cultivations • Buildings, road and railway works in unfavourable geologic and morphologic conditions, which in the past have suffered slidings down (*).	Minimum	− 1
Meadows, grass-lands • Degraded woods and coppices • Forest trees of fruit chestnut groves • Terracings of slopes • Artificial coverings with grassy turfs • Reafforestation up to 3 years • Building and engineering works as for previous classification, but in favourable morphologic and geologic conditions and in the absence of data concerning slidings down.	Mediocre	0
Undegraded coppices • Mixtures of deciduous trees and of deciduous and resinous trees • Resinous degraded woods • Reafforestations in case of more than 3 years • Hydrogeologic reclaim (bridles, control of springs, and so on).	Good	+ 1
Forest trees woods.	Maximum	+ 2

(*) In case of civil private and public works of recent building up, when the storic data can not help the work, it is necessary to limit oneself to consider the geologic (incoherent, pseudocoherent and semichoerent materials; particular conditions of lying of the layers, dislocations and so on) and morphologic conditions (slopes with a great inclination, nearness of very deep slopes or precipices; areas subject to strong erosion, and so on).

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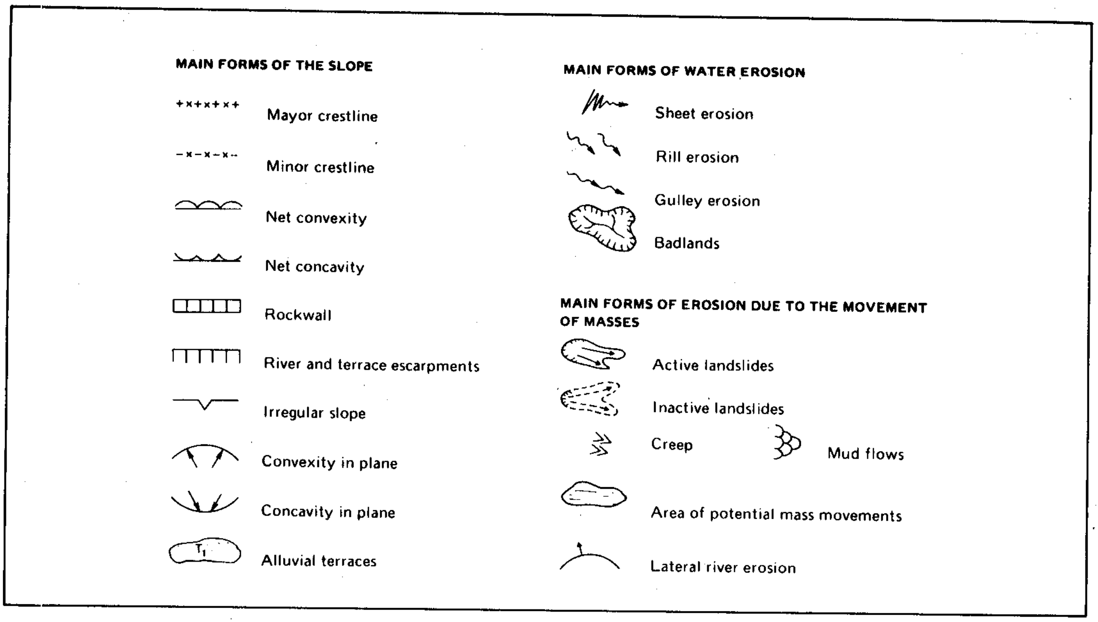

Figure 3

6. Seismic data

The main problems related to the seismic phenomenon are strictly connected with the safety rules as regards the big works of civil engineering (industrial plants, dams, speedways, bridges, and so on). As a result of this in areas where the stability of the slope may be considered precarious or at the safety nature limit, the coincidence or the nearness of seismic epicentrums must be sufficient to warn the engineer before that he begins to operate on the area.

7. Exposition of slopes and climatic conditions

The last two parameters which are to be kept into consideration during the drawing up of the map of the stability of the slopes are the exposition of the slopes and the climatic conditions. The influence exerted by those parameters come out from the research made to draw up the above-listed maps and particularly from the geomorphologic conditions and the vegetable cover.

Particular considerations on those two parameters can be made by researching on areas on the high mountains, where the great daily ranges and the frost and defrost phenomena play a very important role on the alteration and breaking of the rocks.

If all the above listed maps are available it is possible to obtain through successive crossings and overlaps, the final map or map of the stability of the slopes. In the first stage the lithologic map is crossed with that of the strata-attitude and of the inclination of the slopes. The working scheme of this first stage is table I, where to each single item has been ascribed a negative or positive value from the stability point of view.

The combination or algebraic sum of those values enables the definition of a series of theoretical classes which change from conditions of maximum instability to conditions of stability, with all the intermediate stages. This intermediate map drawn up on the basis of the three above said parameters must successively take into consideration also the other parameters and particularly the vegetable cover and the human activity. In other words the map which is obtained with the first crossing (I stage) is overlapped and crossed with that of the actual land-use of the area (II stage). In fact the presence or not of the vegetable cover and the negative or positive interventions of man, sometimes influence in a very determinant way the pre-existing natural conditions.

At this stage it is necessary to add the data concerning the geomorphologic characteristics and the eventual data on the seismic phenomenon; in this way the final map or map of the stability of the slopes is obtained (final stage).

To conclude it is important to say that some possibilities exist to draw up within a short period of time a map of the stability of the slopes in large extensions of land by using electronic data processing systems; such a study which is already in an advanced working stage will enable speed intersections between different parameters which now force the engineer and/or the geologist to spend a lot of time and to a great concentration effort.

Abstract

The slope-stability map is a new type of thematic map. Its construction is based on the interpretation of aerial photographs integrated with field surveys and laboratory analyses.

The main parameters for this construction are: lithology, type and rate of erosion, inclination of slopes, strata attitude, vegetation cover, climatic conditions.

Each of these parameters lead to a specific intermediate map (lithological map, geomorphological map etc.); overlapping these last and considering also the influence of human activity, it is finally possible to obtain the conclusive map regarding to the slopes stability of the studied area.

Zusammenfassung

Die Hang-Stabilitätskarte ist eine neue thematische Karte, die auf Luftbildinterpretation, Feldaufnahme und Laboratoriums-Analysen beruht.

Die wichtigsten Parameter sind Gesteinsverhältnisse, Art und Fortschreiten der Erosion, Geländeneigung, Streichen der Schichten, Vegetation und klimatische Bedingungen.

Für jeden Einflußfaktor kann eine eigene Karte erstellt werden (lithographische, geomorphologische Karte, usw.). Aus der Überlagerung dieser Karten und unter Beachtung der menschlichen Maßnahmen kann schließlich die endgültige Darstellung der Stabilitätsverhältnisse des betreffenden Gebietes abgeleitet werden.

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Résumé

La carte représentant la stabilité des versants est une nouvelle carte thématique établie à l'aide d'interprétations de vues aériennes, de levés topographiques et d'analyses de laboratoire.

Les paramètres les plus importants sont: la lithologie, le type et le degré de l'érosion, l'inclinaison des versants, la direction des couches, la végétation et le climat.

Pour chaque facteur d'influence on peut établir des cartes individuelles, par exemple une carte lithographique, géomorphologique, etc. Tenant compte de l'activité humaine, la superposition de ces cartes permet d'élaborer une représentation définitive des conditions de stabilité des versants de la région étudiée.

Resumen

El mapa de estabilidad de las pendientes constituye un nuevo mapa temático, basado en la interpretación de fotografías aéreas, en levantamientos topográficos así como en análisis de laboratorio.

Los parámetros más importantes que intervienen son: la litología, el tipo y grado de erosión, la inclinación de las pendientes, la dirección de las capas, la vegetación y el clima.

Para cada factor que influye se establecen mapas individuales, o sea un mapa litográfico, geomorfológico, etc. Superponiendo estos mapas y teniendo en cuenta también la acción humana, es factible deducir de ello la representación definitiva de las condiciones de estabilidad de las pendientes en la región estudiada.

Riassunto

Scopo di questa ricerca è stato la realizzazione di una carta della stabilità potenziale e reale dei versanti di un'area campione utilizzando tecniche fotointerpretative. La metodologia messa a punto si basa su una serie di parametri oggettivamente validi: litologia, pendenza dei versanti, grado e tipo di erosione di quest'ultimi, loro esposizione, giacitura degli strati, copertura vegetale e condizioni climatiche. Questi parametri variamente incrociati tra loro hanno portato alla stabilità potenziale o propensione alla stabilità o al dissesto del versante: bisogna poi aggiungere l'attività umana che modificando le suddette condizioni naturali conduce alla stabilità reale.

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