Making Landslides Risk Maps as Monitoring Systems of the Phenomenon Based on Precision Geodesic Measurements

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Key words: Risk maps, hazard, disasters, geospatial measurements, landslides, terrain digital model, geodetic methods

SUMMARY

This paper addresses the realization of risk maps for building a group of models for landslides monitoring.
Using geodesic methods geodesic parameters are determined with high precision, which allow the location of other parameters influence (physical and dynamic, conditioned by environmental factors, geomorphological structure of the area, precipitation etc.) that influence the landslides.

Firstly we studied the landslides process to determine the parameters according to the causes that produces such phenomena and to correlate these parameters to the terrain topographic elements for the elaboration of maps which can be used for decision making regarding the measures to combat the phenomenon and reduce damage. For example, we used the terrain digital model to calculate the volumetric weight, an important physical parameter in the elaboration of the quasi-probabilistic model of the landslide.

SUMMARY (romanian language)

Această lucrare se referă la realizarea de hărţi de risc pentru construirea unui grup de modele de monitorizare a alunecărilor de teren. Prin metode geodezice se determină parametrii geometrici cu o precizie ridicată, fapt care permite localizarea spaţială şi determinarea influenţei celorlalţi parametri care influenţează alunecările de teren (localizare fizică şi dinamică, lucru condiţionat de factorii de mediu, structura geomorfologică de zonă, precipitaţii etc.).
În primul rând, s-a studiat procesul alunecării de teren pentru a determina parametrii în funcţie de cauzele care produc astfel de fenomene şi de a corela aceşti parametri cu elementele topografice ale terenului în vederea elaborării de hărţi ce pot fi utilizate pentru luarea deciziilor cu privire la măsurile de combatere a fenomenului şi pentru a reduce daunele. De exemplu, s-a folosit modelul digital al terenului pentru a calcula greutatea volumetrică, un parametru fizic important în elaborarea modelului cvasi-probabilistic al alunecărilor de teren.

1. INTRODUCTION

The realization of the terrain digital model and of the digital map by accurate planimetric and altimetric measurements can also be used in the calculation of:

- *thickness and volume of the landslide body;*
- *length and width of the landslide body;*
- *partitioning of surface area for the determination of the slide directions;*
- *determining of longitudinal and transverse sections etc.*

The novelty in the realization of this model resides in determining on maps, for each parameter that intervene in the landslide process, of the influence zone, quantified by determining of significant values based on measurements, the correlation between parameters, so that a systemic analysis is allowed (a dynamic system with multiple inputs and multiple outputs). It proves the observability and detectability of the instability zones of the system and the measurability of the perturbing factors. In this context we designed a system in which geodesic measurements are combined with measurements from transducers, this system allowed to establish the correlation between the perturbation factors parameters, their spatial distribution and their influence zoning.

This zoning allowed the use of modern analytical methods such as *finite element* method, using *neural networks* for finding of the most probable values of the periodically repeated geodetic measurements (considered here as *time series*) for highlightening of landslides. This zoning also opens other possibilities for complex and efficient analysis by using of cluster method and development of landslide simulation models (*Jianhua Gong, Hui Lin şi Li Xianhua, Japan, 2008*).

Finally we present the results obtained from interdisciplinary research during TERRARISC project for determining of landslides in Suceava county area. Initially there were no geodesic measurements for the area, so it couldn't be realized a spatial distribution of the influence of perturbing factors, then, due to the geodesic measurements carried out, could be observed a qualitative leap both in the elaboration of risk maps and in the accuracy and efficiency of the analyses, leading to the multidisciplinary approach of the research, establishing at the same time the importance of accurate geodesic measurements in landslide monitoring and extension of the researches toward using of digital photogrammetry and teledetection to analyze the phenomenon.

Landslides are displacement processes of coherent masses of earth slopes, along the plans that separates them from the stable slope, called sliding surfaces. During landslides the rocks move along slopes over distances up to. On steep slopes, especially when the soil is saturated with water, the rocks are moving at a higher speed causing massive disasters.

2. LANDSLIDES

2.1 Causes and identification of landslides

The causes of landslides are varied and very often can not be easily highlighted, detailed and long studies are needed, oftenly interdisciplinary studies because there are many parameters involved in landslides.

Among the causes revealed up to now we mention:

- ***changing of slope stability*** due to *(*base underdigging by erosion or human activity, slope overloading by heavy constructions or material adding to the upper sloper);
- ***water in excess*** (*heavy rainfall, snowfall, springs)*;
- ***natural mechanical shocks***;
- ***changing of land user.***

How do we acknowledge landslides? Slopes with irregular conformation, wavy or stepped surfaces, discontinuities and large differences in small spaces, cracks, small depressions occupied by pools of water and hygrophilous vegetation.

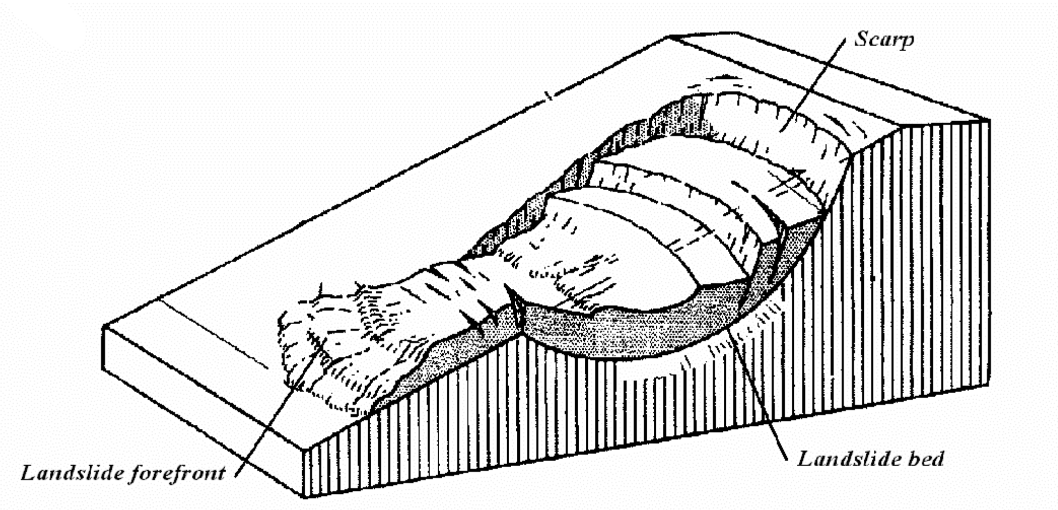

Fig. 1 Landslide on a slope (schematic)

- *Scarp*–the place where the sliding land mass was detached from;
- *Landslide bed*–surface that separates the moving material from the substrate that stands still;
- *Landslide body*–the displaced land mass;
- *Landslide forefront*–the downstream of displaced material.

The main problem in monitoring landslides is identifying them, the influence zone, by means of *geological mappings, explorations using geophysical methods, drillings, rotational shearing tests, etc.* During identification various elements are pointed out: degrees of variation in slopes level, wavy zones on slopes, the existence of limb shaped surfaces on slopes, areas with humidity in excess on slopes, springs or diffuse water emergences especially at the bottom half and at the base of the areas considered to slide, trees with inclined trunks in different directions on the slopes.

The quasi-probabilistic model of the slide is based on analytical models whose principle is the balance between the forces that react on the rock massif.

The probabilistic component of the model results from the uncertainty of the values of the parameters, uncertainty expressed by the standard deviation of the standard values from the medium value.
The medium value and the standard deviation for each parameter are obtained using the topo-probabilistic assessment of the parameters, based on the data obtained from the monitoring networks designed by means of probabilistic models.

2.2 Evaluating the probability of a slide

Slides on curved surfaces are rotational slides, which forms in rocks plastic enough to yield without excessive loss of resistance in maximum effort concentration areas. Because of this the efforts are distributed relatively even along the potential sliding surface.
The main forces that generate the rotational slide tendency are represented by sliding forces, which include the sole weight (G) of the rocks in the potential sliding body, and also the static loads applied on the surface of the batter or slope. The seismic component can act as an accidental sliding force (figure 2), which has the form kG, the symbol k indicating the seismic coefficient depending on the seismic degree of the area.

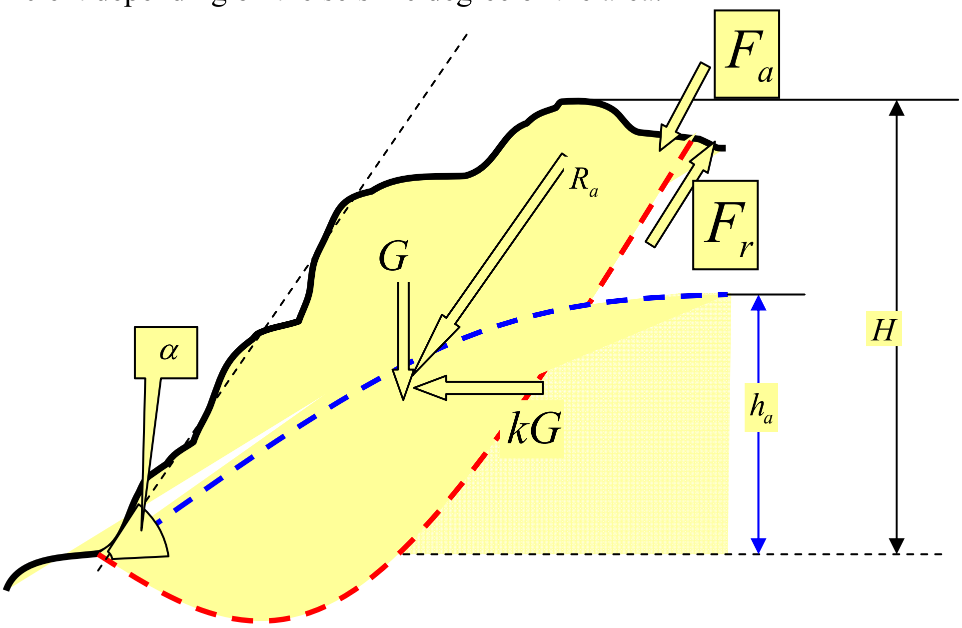

Fig. 2 The main forces in the hypothesis of a rotational slide
(according to the research project TERRARISC)

The resultant R_a induces the **shearing forces** F_a of the shearing efforts τ_a tangent to the potential sliding area in each point of the rotation surface. **The resistance of rocks at shearing loads** (τ_1) along the potential sliding surface generates the resistance forces F_r. The values of the forces F_a and F_r varies along the sliding surface and, because they can not be exactly determined, they must be accepted as random variable whose values have a defined distribution in a given interval.

The probability (P_s) that the slope remains stabile or the confidence in the **stability of the slope (batter)** is given by the probability that the sliding forces would remain, in any situation, smaller than the resistance force, that is:

$$P_s = P[F_a < F_r] \quad (1)$$

The probability or the sliding risk (P_a) is equivalent to the probability that the sliding forces would become bigger than the resistance forces, that is:

$$P_a = P[F_a > F_r] \quad (2)$$

The trust that can be conveyed to the calculated probability depends on the number and quality of the tests done to determine the geo-mechanical parameters, on the piezometric data, on the option on the localization and the shape of the potential sliding surface, and also on the suitability of the analysis model used. To simplify things, the probability of sliding of a slope with the inclination α can be accepted as equal to the possibility that the inclination of the slope would be bigger than the limit or critical inclination α_c, that is:

$$P_a = P[\alpha > \alpha_c] \quad (3)$$

From a probabilistic point of view, the critical angle α_c is a function depending on the following independent variables: *volumetric weight* ($\overline{\gamma}$)*, cohesion* (c)*, internal friction* (φ)*, slope height* (H)*, external static load* (q)*, maximum height of the piezometric volume* (h_a)*.*

The simplified solution neglects the eventual correlations between the mentioned variables and admits that each variable introduced in the calculations follows the normal repartition. The deviation of some of the variables from the normal repartition has no considerable effects if errors of ±0,001 are accepted for the determined sliding risk. A sufficiently big number of values *n*, which groups around the medium value, with standard calculated deviations, is determined for each independent variable by means of experimental trials or field measurements. For the volumetric weight of the rock in the entire rock body delimited by the surface of the slope and the sliding surface, using the experimental values, there can be calculated: *medium value* $\overline{\gamma}$*, standard deviation* s_γ*.*

The medium values $\overline{\phi}$ and $\overline{c}$, for the internal friction angle and the rock cohesion, along the potential sliding surface, and the corresponding standard deviations s_ϕ, s_c can be obtained similarly.

If on the upper part of the slope, the surface of the land is plane and horizontal, the height H is constant. If the morphological surface on the superior part of the slope presents considerable variations in level, the medium height $\overline{H}$ and the standard deviation s_H must be calculated.

The fluctuations of the hydrostatic level, measured by means of examination drillings or using other hydrogeological methods, are grouped around the medium value $\overline{h}_a$, with the standard deviation s_{h_a}. For evaluating of the maximum effect of sliding risk, the maximum value ($\overline{h}_a$) of the possible piezometric level in specific conditions of the batter or the studied slope, can be introduced in the calculations.

Depending on the medium values of the mentioned geo-technological variables, it can be demonstrated (Sage, 1977) that the medium value of the critical inclination $\overline{\alpha}_c$, for a batter or a slope without tension fractures on the upper part and with an aquifer horizon drained towards the base of the excavations, can be estimated using the relation:

$$\overline{\alpha}_c = \frac{K \cdot \overline{c}}{\overline{\gamma} \cdot \overline{H} + q} + \overline{\phi}\left(1{,}2 - 0{,}3\frac{\overline{h}_a}{\overline{H}}\right) - 7 \qquad (4)$$

in which q represents the supplementary static load applied on a vertical direction to the upper part of the slope, and K is a transformation coefficient, which becomes $K = 445$ if the parameters introduced in the calculation are expressed by *tf* and *m*. The probability of sliding for a slope with the inclination α with values between the limits:

$$\overline{\alpha}_c - 2s_{\alpha_c} < \alpha < \overline{\alpha}_c + 2s_{\alpha_c} \qquad (5)$$

can be estimated (Sage et al., 1977) using the relation:

$$P_a = 0{,}45\sin\left\{\left[\overline{\alpha}_c\left(\frac{s_{\alpha_c}}{45} - 1\right) + \alpha\right]\frac{45}{s_{\alpha_c}} - \overline{\alpha}_c\right\} + 0{,}5 \qquad (6)$$

which, even though it doesn't have a theoretical basis, defines an pointed arch shaped curve which passes through the points $\overline{\alpha}_c$ and the two standard deviations above and below the medium value. The limit sliding probabilities are defined using the following inequalities:

$$\alpha < \left(\overline{\alpha}_c - 2s_{\alpha_c}\right); \quad P_a < 0{,}05 \qquad (7)$$

$$\alpha > \left(\overline{\alpha}_c + 2s_{\alpha_c}\right); \quad P_a > 0{,}95 \qquad (8)$$

The evaluation of the sliding probability of a slope with the inclination α (6) is based on two categories of parameters with specific variability in space and time:

- **field parameter:** *vegetation covering, land lithology, land morphology, land hydrophysical characteristics (numerical), anthropic risk factors.*
- **parameters from the monitoring system:** *rainfall (mm/year or l/s · m^2 · hour), temperature (^{0}C), maximum value ($\overline{h}_a$) of the piezometric level.*

The values of both parameter categories are stocked into the data base with specialized structures depending on the modeling, stimulating and maximum risk zone forecasting services.

Field parameters

There are two categories of field parameters, alphanumeric and numeric, they are used to define the characteristics of the rock body that is at risk of sliding.

Alphanumeric parameters

In the alphanumeric parameters category we mention the vegetation cover and the lithology of formations from which the studied rock body is composed.

The vegetation cover conditions mainly: the amount of infiltrated water, the erosion state of the covering formations

Variable in time and space, the vegetation cover data are stored in data base as alphanumeric values (eg. pasture, forest, etc.) associated with spatial-temporal coordinates (x,y,z,t).

The lithology formations is used to clarify the formations geological structure, together with information on relief (faults, cracks, etc.).
Practically invariable at the study scale time of today landslides, the spatial variability of lithology expressed by the rock types (eg. clay, sands, etc.) causes geomechanic parameters variability. The observation points for determining the lithologic characteristics of geological formations are the outcrops and the geotechnical and hydrogeological drills.
In the data base are introduced the descriptions of outcrops and lithological columns for drilling investigations, elements that are used for the elaboration of geological sections and 3D parametric models.

Numeric parameters
The numeric type field parameters are grouped in three categories:
land morphology, numeric described by: slope angle: α, in sexagesimal degrees; slope height: H, in meters;

Lands hydrophisical and geomechanical characteristics
- Porosity: n in %, Permeability: K_p, in darcy or m^2; Humidity: w, in %; Hydraulic conductivity: K, in cm/sec. or m/day; Maximum height of piezometric level: h_a, in m; Volumetric weight : $\overline{\gamma}$, in KN/m^3; Cohesion: c, in KN/cm^2; Internal friction: φ, in sexagesimal degrees;

Anthropogenic risk factors:
- external static load: q, in KN/m^2.

For all these parameters is important both the spatial and temporal variability. The evaluation of spatial-temporal distribution is made in two versions depending on the solving type of the probabilistic model: global (by medium values) in case of analytical solutions, topo-probabilistic (by distribution maps) in case of numerical solutions.

Comprehensive approach to assess spatial-temporal distribution of the numerical parameters requires the association of each parameter values with the complete structure of spatial and temporal location: x, t, z, t.

Parameters from the monitoring system
The parameters resulted from the monitoring system, that are used in the quasi-probabilistic model, are represented by: temperature, rainfall and the value of the piezometric level. Their spatiotemporal fluctuation is considerable and it is determined by measurements made in observation points chosen after preliminary monitoring campaigns in a high-density and extended network. *(Dislocation – u; Direction; Speed – v; Temperature – T; Humidity – h; Forces – F; Pressures - P (of the solid or filtration material etc.)*

Landslides monitoring - criteria and analysis of the optimal choice for usual sensors:
- Metrological criteriae: measuring range, sensitivity, resolution, liniarity, hysterezis, response time, reliability, size adn mass;
- Criteria specific to monitoring conditions of landslides: price, reaction to environmental conditions, temperature, humidity, corosion, mechanical stress, installation conditions, operating mode (for demanding training or assistance).

t1=level transducer
t2= temperature transducer
t3=inclinometer transducer
t4=rainfall transducer
mc=control module
SA=power source
PA=acquisition plate
UC=central processing unit
mr=radio modem
SR=radio station
BA=power unit

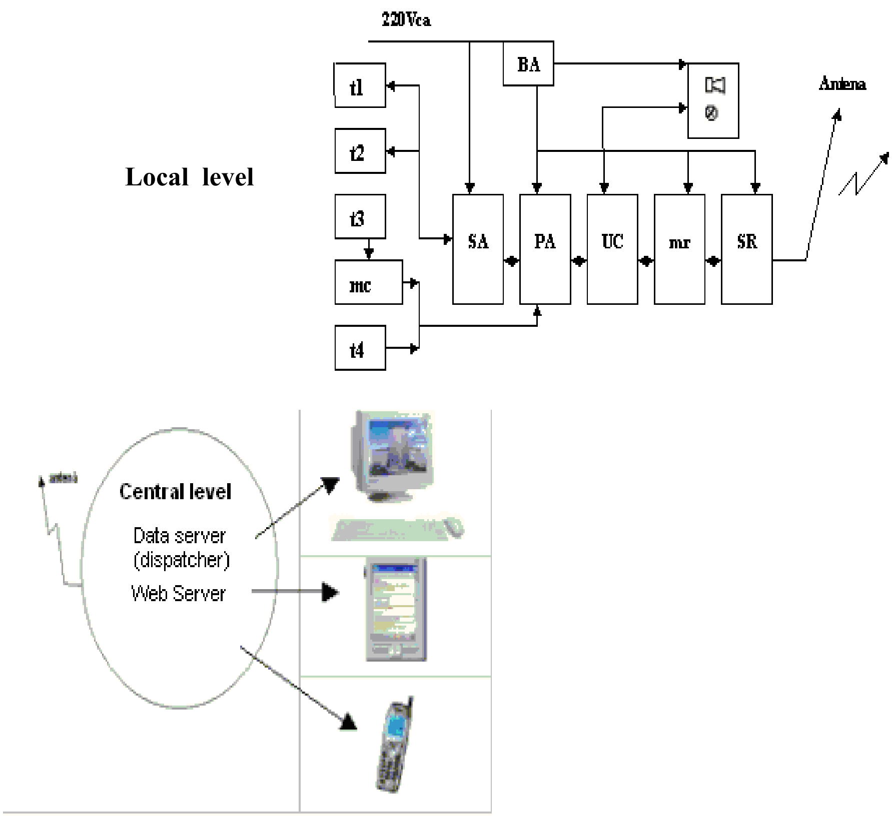

Fig. 3 Architecture of the system used for landslide risk management (according to the research project TERRARISC)

Local subsystem

The local subsystem is composed of: a) Transducers, sensors, detectors etc., b) Local equipment: control module, adapter, double power sources, monitoring equipment, data transmission radio station, antenna.

As a result of the debates that have taken place after the field visit, it has been agreed that the following parameters representative for the monitoring of the slope should be measured: inclination in 4 points in accordance to two axis, temperature, rainfall quantity, groundwater level etc.

Fig. 4 Sensors system for taking the field data

2.3 Classical and modern models used in the analysis of landslide zones behavior

Landslides can be interpreted as spatial deformations of an area affected by the aforementioned applications. The classical approach in this case take is considering a quasi-static model and geometric analysis methods (Niemeier, 1988). Determinations based on geodesic measurements in the classical approach, characterizes mainly the effects of landslide phenomenon even in the case of the kinematic model, which highlights the displacements speed and acceleration in discrete points located for area monitoring (traking marks) reported to points located in the stable area (traking benchmarks)

In dinamic models the approach is systemic and the relations between the forces that induce the deformations are highlighted (Heunecke, 1994), so the system analysis can be performed by a nonparametric approach – black box model – or a parametric one – explicit model.

In time monitoring of landslides for the slope system, systemic point of view, is a complicated issue because the target of the investigation is represented by systems with multiple inputs and outputs. This involves determining the internal complexity, highlighted by the interactions of control parameters, meaning certain criteria such as field parameters: vegetation cover, land lithology, land morphology, land hydrophysical characteristics (numeric); anthropogenic risk factors, parameters from the monitoring system; rainfall (mm/year or $l/s \cdot m^2 \cdot hour$), temperature (°C), maximum piezometric level ($\bar{h}_a$).

Consequently, it becomes necessary to describe these interactions, particularly regarding the study of dynamic behavior, as an algebraic and geometric investigation of a mathematical model correctly defined.

Classical variational methods have proved unable to resolve a number of actual important issues, to whom landslides also belong, so it is necessary a parametric analysis, the most appropriate modeling method for analyzing structures in the sliding zone and the disruptive factors is the finite element method presented in the first part of this chapter. Based on periodical geodetic measurements, which can be characterized as time series, using the finite element method can be revealed the changes in the coordinates of individual points in the slide zone and the input parameters that describe the behavior of the system under disturbances actions.

Processing experimental and observation data involves the use of special analysis methods, covered by the following areas of mathematical statistics: descriptive statistics, correlation analysis, regression analysis, spectral analysis, statistical hypothesis testing, modeling and prediction.

The fields mentioned above are as many function classes, in which will be implemented in software modules designed realize a decision support system (DSS).

For monitoring the behavior of landslides the displacements of a set of points located at characteristic points are studied. In this domain, an important role is played by the accurate determining of spatial positioning of the characteristic points on various objects, by means of contactless measuring methods and, if possible, in the shortest time.

In most of cases, geodesic measurements results (eg. directions and distances measurements) are used in previous calculations to determine points coordinates. Since the individual measured values are affected by random deviations (random errors) represented by standard deviations of measured values, these deviations will alter the calculated function. Deviations of measured values will propagate in the calculated parameter (error propagation law) - (Coşarcă, 2007).

The basic geodesic methods for monitoring landslides behavior in time, were distinctly developed for monitoring the behavior in the horizontal and vertical plane. These methods

require specialized personal, precision equipment, favorable weather conditions, and appropriate software for processing the parameters and interpretation of results. Field data collection is time consuming and the processing is made at a later time.
Geodesic methods have the advantage that provides information both about the landslides and on surrounding land. The monitoring geodesic system of landslides is general composed of two independent nets: a planimetric and an altimetric one.
The altimetric system consists of developed geometric leveling lines.

Support planimetric network points are materialized by concrete pilars equiped with forced centering systems, thermicaly isolated and having the fundation on the bedrock to ensure long time stability. GPS technology is not yet a standard method for monitoring the movements in the sliding zone. The use of this technology is still in the experimental stage.
The compensation of support networks by the method of least squares
Through GPS technology a point P(X,Y,Z) is determined within a global reference system on WGS-84 ellipsoid. In the case of the support networks realized with GPS technology, the position of a point *j* is determined relatively to a point *i* by measuring a vector $\overline{X}_{ij}$ (named base), or the components of this vector $\Delta X_{ij}, \Delta Y_{ij}, \Delta Z_{ij}$

3. APPLICATIONS OF TEORETICAL CONSIDERATIONS IN A PRACTICAL EXPERIMENT

Starting from the theoretical considerations presented in the first part of the paper, regarding classification, state parameters, perturbing factors, that causes the landslides in this case study, we applied the suitable mathematical models to combine the sensor-based determinations with accurate geodesic measurements. The novelty of this approach resides in the shift from geometrical analysis models (Niemeier quasi-static model) or dynamic models (Heunecker) to a complex analysis based on dynamical systems analysis with multiple inputs and outputs.

The area proposed for monitoring
North-eastern slope, the most affected by landslides, is presented as a monocline with north-eastern fall, with a slope length of about 250÷350m and a width at the level line of about. The slope is more pronounced immediately below the slope cornice, decreasing gradually downstream. The N-E slope of Suceava city, contained largelly between Petru Rareş Street (in extension with Petuniilor Street and with cornice of Zamca plateau

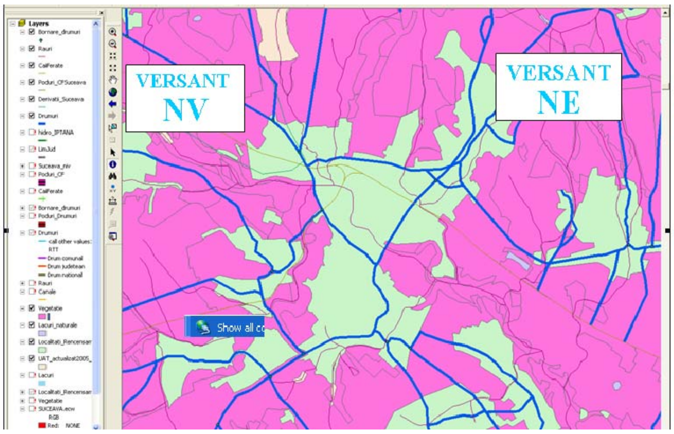

Fig. 5 Suceava - The area proposed for monitoring

upstream of Mihail Sadoveanu Street) and Traian Vuia represents the connection talus between the upper platforms of the city and the lower terrace of the Suceava River

The N-E slope was affected over time by zonal landslides on a length of about 2000m on the line level and a width of 300÷400m along the line of greatest slope.

Geomorphologically, the location is situated on the fringes of a high plateau, separated from Suceava city plateau by Pârâului Târgului creek.

The castle plateau has heights about 333 mdMB, that can be correlated with medium terrace in the central zone of Suceava city, with heights about 340 mdMB. The castle plateau continues towards Ipoteşti (with an artificial separation represented by the eastern side of the defense) and can be assimilated with the structural surface of the Cetate – Ipoteşti – Bosanci cuesta. On the castle plateau stands out two quasi-plane step levels differentiated by 3÷5m apart. The northern slope of the castle is represented by the steep of the mentioned cuesta and has large inclinations of 32°÷40° towards north and north-west.

The angle was measured with a transducer called inclinometer. The inclinometer is an equipment for measuring the movements of the soil, slopes and buildings to determine their deformation and stability. The inclinometer used was that of the two measuring axes type. This has electrolyte sensors and advanced electronic filters encapsulated in a plastic tube. This tube has external guides for mounting in the wells so to preserve the two measuring axes after they are introduced in the well. The inclinometer can be equipped with rolers at each end for an easier slide in the well. The hole displacement measuring system consists of a chain of inclinometers to cover the entire depth of the well. This inclinimeters are connected by a flexible cable to assist their handling. The information from the sensors chain in a well provides the well profile with vertical reference. Comparing the data obtained over time, can be calculated the displacement and deviation of the inclinometer. The embedded signal processing system, eliminates the negative effects due to cable length.

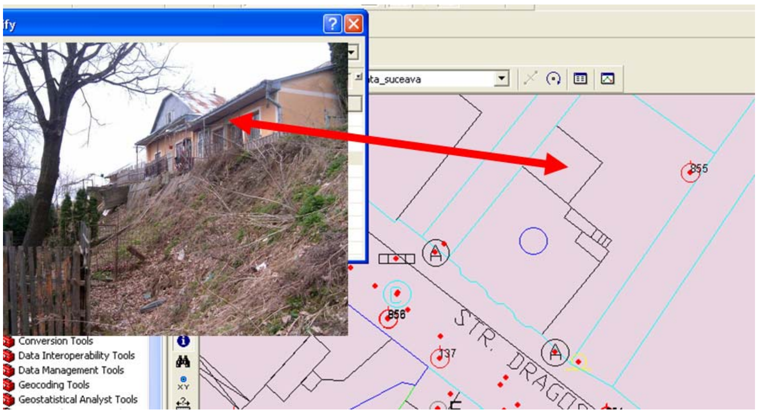

Fig. 6 House in Suceava - The area proposed for monitoring

According to the calculations of forecasting movements in wells with monitoring inclinometers, the warning of instability, in meteorological and hydrogeological conditions of the registration period considered so far, will rise only for values of displacements over 18÷20 mm, so the Sadoveanu slope was stable during the monitored period.

TERRARISC system designed by an interdisciplinary researcher team from the Institute for Computing Technology (ITC), IPA SA, University of Bucharest, Faculty of Geology and Geophysics and SSI Bucovina for landslide risk management, is a complex system that allows online acquisition of environmental parameters, provides data entry of the context of landslide phenomenon in a relational database, uses a complex system of data analysis based on probabilistic modeling and online analysis techniques of databases for simulations, necessary forecasts for decisions and population informing.

Unfortunately, although this system targeted the integration of the data in a specialized GIS, it has not provided the spatial positioning of sensors, wells and the other devices for determining the model parameters, and the main problem of the dynamic modeling is system identification. In our case the determination of parameters that describe the system is realized by sensor measurements and by accurate geodesic measurements, there for we have a parametric identification, the transfer matrix being determined by measurements.

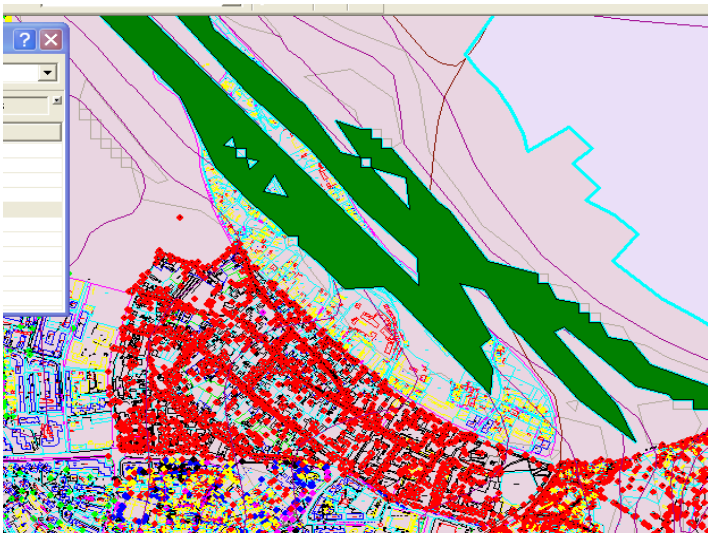

Fig. 7 Highlighting the slide area on the digital map

So was imposed by necessity the spatial correlation, based on geodesic measurements, of parameters with terrain topographic elements in order to achieve digital maps and the integration in a specialized GIS (see Fig.7). We present in the following the completion of the researches in TERRARISC project with the geodesic measurements we made.

Consider a set of points P_i (x_i, y_i, z_i) located on the analyzed slope, configured in Fig.12a and we aim to describe the current state of the analyzed slope by geometrical (geodesic measurements) and mechanical (sensors measurements) dimensions. We realize in steps the digital model of the terrain, first by level lines (see Fig. 8), then by digital models (see Fig. 9)

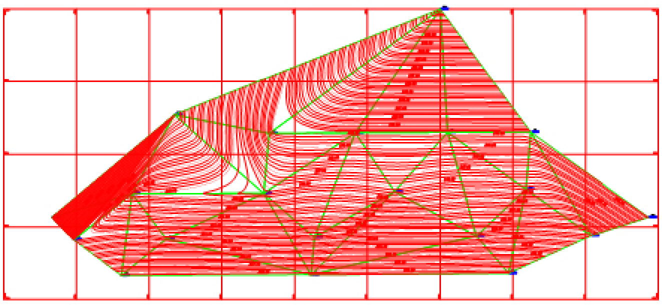

Fig. 8 Measured points set and level curves tracing

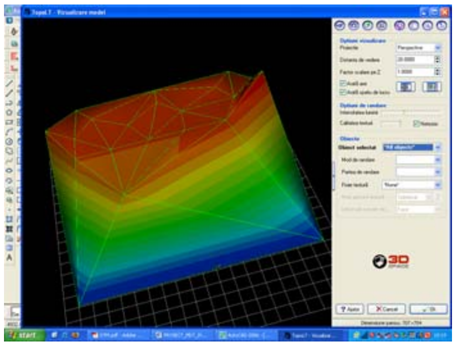

Fig. 9 Digital models of the terrain

Based on this models we calculate the volume (Fig.10) for mass determination, to find the volume weight ($\overline{\gamma}$) which along with the other parameters contributes to the construction of the quasi-probabilistic model.

The methodology for tracking the landslides is that of high precision geometric leveling class I and class II, using Koni 002 precision level, which provides ±0,2 mm/km. It can be noted deviations from the tolerance at the marks on towers and tanks due to modifications of the reticle positioning on marks for which subsequent work was made. For the rest of the measurements, the values were within the annual variations from previous recordings. In can be observed in tracking records of various objectives mentioned above. The data measured on reference marks were within prescribed tolerance instructions: **T = ± 0,15** $\sqrt{N_s}$ **(N_s= stations number/polygon) for cl. I.**

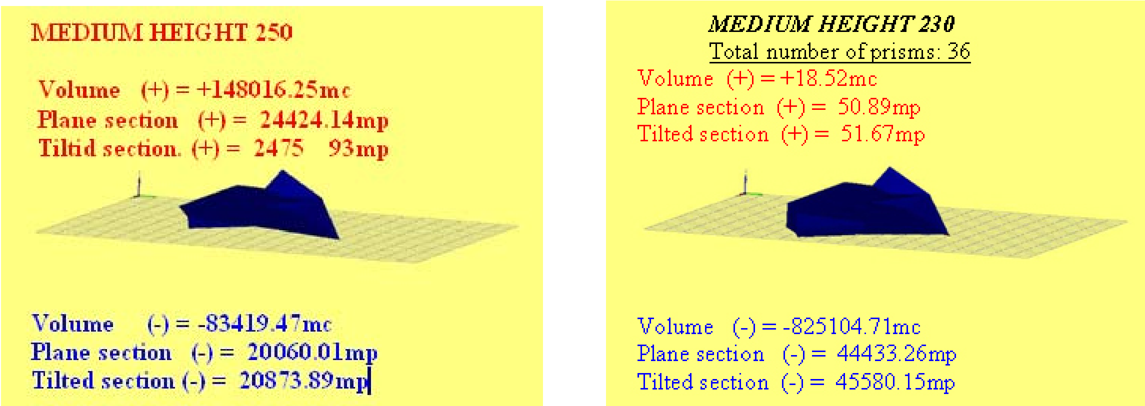

Fig. 10 Volume calculus at medium height 250 and 230 m

$$\mathbf{T = \pm\ 0{,}40}\ \sqrt{N_s} \quad \textbf{(}N_s\textbf{= stations number /polygon) for cl. II.}$$

- Medium mark erors/entire zone: SH = 0,13 mm/1 km.
- Medium mark erors/survied zone: SH = 0,30 mm/1 km

Azimuth and distance observations were made with Leica TC805 geodesic station, one of the most accurate existing equipment. Angular measurements were observed by series method, with two series for the network points and a series for the landmarks on store dams. The field data were then processed on computer, resulting, by comparison with the coordinates of the previous measurements series, the displacements on X and Y directions for each landmark. In 2008 we determined the coordinates of the new piezometric wells. During measurements in 2009 the temperature ranged between +26°C and +34°C, the sky was sunny, without wind. The results of the measurements is associated with the graph (Fig.11) and we

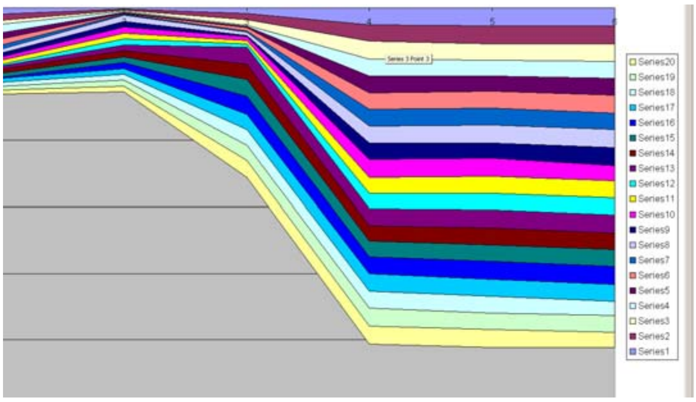

Fig. 11 Landmarks displacement graph as function of rainfall

can see the correlations of these displacements, especially after rainfall. We can see the valences of the spatial distribution, influence of disturbance, then, when geodesic measurements were carried out, we can see the qualitative leap both in making the risk maps and in the accuracy and efficiency of analysis carried out, leading to the conclusion of multidisciplinary approach of the researches, also stating the importance of precision geodesic measurements in landslides monitoring. Although the monitoring period was relatively short, the insertion in the project, even at a late stage, of geodesic methods proved fruitfull and pointed out the necessity to extend the researches for using digital photogrammetry methods and teledetection in landslides monitoring.

4. ELABORATION OF NATURAL RISK MAPS BASED ON MEASURING TECHNIQUES

-The elaboration of the hazard map has been outlined according to the Law 350/2001 (art.18).
-The software used for elaborating the natural hazard maps are: ArcGIS vr. 10/9.3; Surfer vr. 9.7; Global Mapper vr. 11.
- The data used were translated (digitized or using Pattern Recognition algorithms) from raster format in vector format, to homogenize the workflow. The data required are: lithologic map, geomorphological map, geological map, hydrological map, seismic activity map, map with surfaces occupied by forests (forest domain), anthropogenic areas map.

After getting the data (raw format) these are verified and processed with a calculation formula (9) established by Law 350/2001, which enables to calculate and get a score. This score is rated in a scale from 0 to 1 (ie 0; 0.2; 0.54 etc.)

$$K(m)=\sqrt{\frac{K(a)\cdot K(b)}{6}}\cdot\left[K(c)+K(d)+K(e)+K(f)+K(g)+K(m)\right] \quad (9)$$

-Data processing: for each criteria (lithological, geomorphological, structural, hydrological, seismical, anthropic) is calculated a score (scale 0-1) which is assigned according to the characteristics and stability of the area. After obtaining the map with the slopes in the area of interest, there is possible that errors could occur (topological, shp corruption, etc.) and is recommended to check carefully in order to not alter the final result. The next step consists in classification and extraction of the slopes according to the risk class. Then, every class receives a risk index corresponding to the class it belongs.

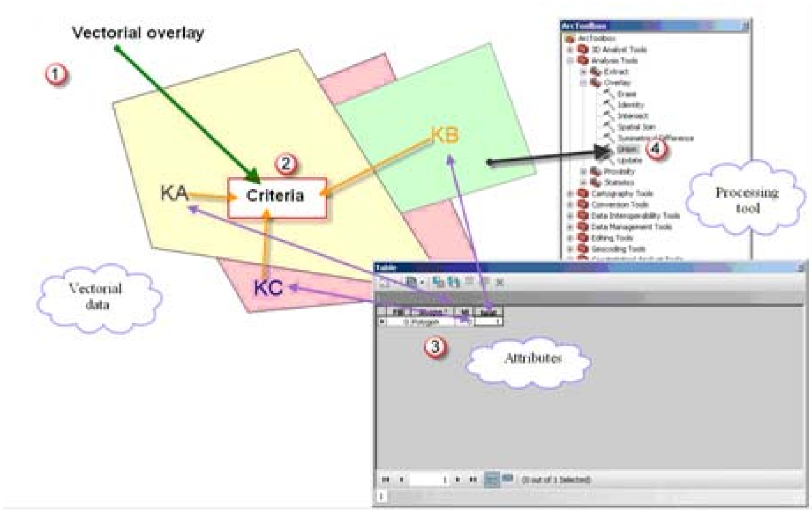

Fig. 12 Calculation model

Six indices of risk are identified, assigned to the six classes: 1. between 00 - 20: risk 0; 2. between 20-50: risk 0.35; 3. between 50-120: risk 0.85; 4. between 120 - 150: risk 0.75; 5. between 150 - 170: risk 0.25; between 170 > 170: risk 0.05.

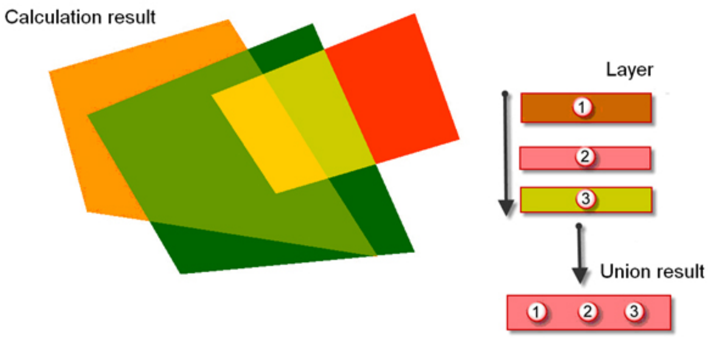

Fig. 13 Overlays explanation

After index calculation and assigning, will follow the integration of each criteria in a single entity (shp), in order to make the calculation using the formula mentioned above.

So it will be used Union as an overlay tool (see Fig. 12 and Fig. 13).

The final map is shown in Fig. 14 and is the result of iterative overlapping and classification.

5. CONCLUSIONS

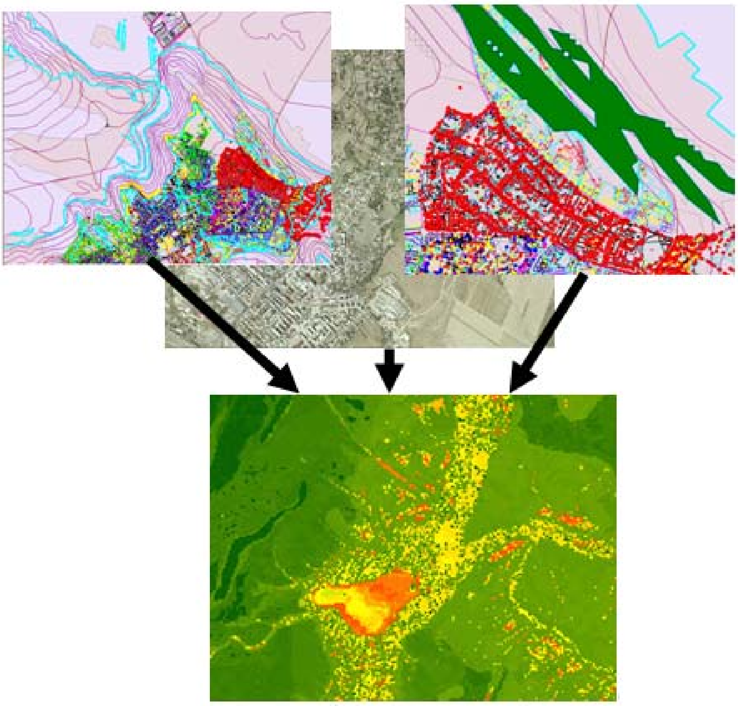

Fig. 14 Digital map of landslides for the studied zone

Massive instability phenomena of the earth's events change the landscape by the dominant action of gravity on the downhill portions of the earth's crust is relatively common phenomena in many parts of the world, with the most important economic implications. In order to prevent and sometimes catastrophic implications of events such massive instability of the ground, is necessary an extensive program of monitoring by methods, techniques and equipment to cover a wide range of unstable phenomena, depending of the conditions and natural environment. Landslide risk management involves a complex treatment decision-makers and enable people to collaborate, to base scientific decisions, react positively to operating strategies. Such an approach is only possible on the basis of which to use information technologies, communications and data acquisition technologies online.

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