The first phase of the Landslide project is coming to an end. Partners have in this phase worked on the very development of the innovative Landslide Hazard Assessment Model and Software.

This has been a quite complex task and has required accurate planning of the activities for its achievement. The Landslide Hazard Assessment Model and Software is constituted of three core modules: soil moisture dynamics, landslide hazard computation, and web-based management of input/output data. In the first two modules, the mathematical models have been solved by appropriate numerical approximation methods.

The third module consisted in developing a sophisticated web application which:
- is able to acquire weather forecast data from usual prediction systems like GFS or ECMWF, to acquire weather data from regional weather meteorological stations, and to deliver landslide hazard maps to local and regional authorities, in an automatic and dynamic way (on-line operation);
- offers a graphical user interface for the off-line operation of the system, where the landslide hazard can be computed from an hypothetical future weather condition scenario. This provides for a useful tool in the prevention activity with particular reference to the mitigation measures of the landslide risk arising from global change.

The system also allows for statistical analysis of day by day landslide hazard indices, and of their spatial distribution provided by the on-line operation. The latter constitutes a new medium and long-term landslide hazard index, that can be obtained only from the time-series of the proposed dynamic index and that will be object of an accurate scientific investigation to check its usefulness and correlation with standard static hazard indices.

Finally, a number of preliminary steps carried out in the development of the three modules have resulted in additional deliverables, such as: the definition of a standard method for the adaptation procedure of the model, that can be extremely useful when extending it to new territories, and; databases of hydrogeological and historical landslide events, related to the four test areas, being also relevant for further scientific/technical investigations on soil moisture dynamics, and on landslide hazard computation.

As regards the adaptation procedure, it also requires the measurement of the soil water content at different depths (from 10-20 meters), that can be obtained by usual “in situ” techniques: Tensiometer, Electric conductivity method, Dielectric constant method, Neutron scattering method. The method chosen by the Landslide project appearing to be the most appropriate one is the direct method where, by drilling operations, a sample of the soil at different depths is obtained and analysed by laboratory tests. In effect, such test (2-4 tests for each basin equipped with 2-3 weather stations) allows not only to assess the water content at different depths, but also to detect other soil features relevant for the implementation of other project activities (hydraulic conductivity of the soil, diffusivity of the soil, etc.). The effective numbers of drilling tests, including drilling depth, in the respective test sites were decided in response to the outcomes of the first drilling test. In section 3 you can read more about the drilling process, carried out in the project’s four test sites.

Enjoy reading!
Pierluigi Maponi
Coordinator of the Landslide Project
The weather conditions influence profoundly human activities, in some cases they take on particular strength and are able to harm population or property. Heavy rains, combined with the particular conditions characterising a region, can cause a landslide or flood: this is called 'hydro geologic hazard'.

In the last years, the hydro geologic instability has gradually increased throughout Europe: today the landslide risk is a real danger for both the inhabitants of mountainous and hilly regions and for infrastructure in that area. In addition, climate change cause more and more intense weather events that represents one of the first causes of landslides.

In this project, the landslide hazard is taken into account with respect to the weather conditions and the features of the soils. In particular, the project objective is the development, the implementation and the testing of an automatic software for the dynamic evaluation of soil-moisture content and the corresponding prediction of the daily hazard of landslides in the European territories. So, this project should combine the dynamics of soil moisture, with a model that calculates the slope stability for a quantitative evaluation of landslide risk.

The dynamics of soil-moisture is a complex phenomenon depending on atmospheric conditions, geomorphological features of the region under study and the corresponding land use. When the water reaches the soil surface, for example during a thunderstorm phenomenon, immediately it penetrates, adhering to the grains that constitute the soil and saturating them. In this situation, gravitational action prevails and the water infiltrates into the soil, meeting several layers characterized by different permeability. The first layer to be crossed is generally unsaturated and it is called the evapotranspiration zone (or unsaturated zone) because here the evapotranspiration takes place. This phenomenon considers the amount of water that in a given period of time, passes from the soil to the atmosphere because of the plant transpiration and evaporation from the soil. The evapotranspiration layer is followed by the capillary fringe where pores are only partially occupied by water. This layer is followed by the aquifer or saturated zone where the water fills all voids and flows into the ground with a movement predominantly horizontal (infiltration). The last layer is the impermeable substrate and it is made by fine materials such silt, clay or by non-fractured rock formations. The water infiltration into the soil can be formally described by diffusion equation models arising from Darcy's law and mass continuity law: throughout these two principles in fact, it can be obtained 'Richards equation' which can be written as:

\[
\frac{C(\psi) + S_n \frac{\theta(\psi)}{n_c}}{n_c} \frac{\partial h}{\partial t} = \frac{\partial}{\partial x} \left( K_{xx}(\psi) \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_{yy}(\psi) \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_{zz}(\psi) \frac{\partial h}{\partial z} \right) + W - ET, \tag{1}
\]

where \( C(\psi) = \frac{dn}{d\psi} \) is the specific capillary capacity, \( S_n \) is the storage coefficient, \( K(\psi) \) is the hydraulic conductivity, \( W \) is the recharge and it is related to the rate of precipitation, \( ET \) is the evapotranspiration and it represents the loss of water due to the evaporation and traspiration of plants (it can be estimated by Penman – Montieth equation).
Richard’s equation cannot be solved analytically if not assuming some simplifications: in order to obtain an approximation of the solution, the problem can be treated numerically, approximating the differential equation by a system of equations with a finite number of unknowns. After deducing a discretization of the space and time domain, applying the finite difference method to Richards equation, we can obtain a non-linear system of equations where the uniqueness of the solution is ensured by the Neumann boundary condition. This mathematical model depends on the weather data and on the soil vegetation, but in particular it depends on the geotechnical features of the region under study such as the granulometry, which defines many different textural classes of the soil on the base of its solid particles diameter. When all these parameters are set, a numerical approximation method must be used for the computation of the soil-moisture dynamics.

The landslide risk problem consists of computing the so called ‘Safety Factor’ which is given by the ratio between the forces that prevent the slope from failing and those that bring the slope to collapse: in particular, the last forces depend on the soil saturation that will be given by the solution of the soil moisture model. The factor of safety F is a hazard index; in fact, it measures the resistance of inclined surfaces to failure by sliding or collapsing. Roughly speaking, a factor of safety larger than 1 indicates stable conditions, whereas a factor of safety smaller than 1 indicates unstable ones. In particular when $F = 1$ we will say that the slope is at the point of failure.

Such a project can consider two different mathematical models to compute the safety factor: the ‘infinity slope model’ for large scale landslide hazard in order to create quantitative hazard maps; and the ‘method of slices (3D version)’ for small scale landslide hazard analysis. In particular the hazard maps obtained with the infinite slope model can be used from the users to determine a smaller zone where a small scale landslide hazard analysis can be done with the limit equilibrium analysis model.

The infinite slope model describes the stability of slopes with an ‘infinitely large failure plane’ approximately parallel to the slope surface. The resulting formula for the safety factor is:

$$F = \frac{C + (z\gamma - z_w \gamma_w)\cos^2 \beta \tan \phi}{z\gamma \sin \beta \cos \beta}$$

where $C$ is the effective cohesion; $\gamma$ is the unit weight of the soil; $\gamma_w$ is the unit weight of water and it is equal to 9.81; $z$ is the depth of the failure surface; $z_w$ is the height of the watertable above failure surface; $\beta$ is the slope of the inclined surface; $\phi$ is the angle of internal friction.

In the method of slices a more detailed analysis is performed by using a discretization of the slope under study. However, we omit the description of the details of this method in order to avoid a very technical discussion.

The expected outcome of the LANDSLIDE project is the development of a computer model able to predict the daily hazard of landslide on the basis of weather forecasts and then to send information promptly to the departments of civil protection through automated software, so that they can activate measures for monitoring and emergency management.
E-platform architecture and design in the LANDSLIDE project

During the first year of the project lifetime the partner team from the Institute of Information and Communication Technologies (IICT-BAS) started the collection of all data in one GIS database. This was done to allow the model, developed by the University of Camerino in Italy, to be able to start to validate and test its functionalities. A summary of the software use case model is presented in diagram 1.

The main actors are divided in three general groups in the system. The first group is dedicated to project partner users, the second is dedicated to the GIS administrators of the system and the third which is public is oriented to the WEB users of the system.

The system architecture is made in a way that the WEB site can dynamically generate map content and present any kind of spatial data or attribute query for it. The architecture is done in a way to be compatible with any kind of platforms (UNIX, Windows etc.), with J2EE compliant server. The tool can be run on any JAVA enabled Internet browser or standalone, on any platform with JRE 1.1.8 or greater for SUN Microsystems.
Drilling process carried out in the four LANDSLIDE test sites

Test site 1: Peloponnesus – Greece

Two exploratory boreholes BH_1 and BH_2 were carried out from 9 to 12 of June 2015 under very good weather conditions at Panagopoula test site (NW Peloponnesus, Greece).

The Drilling machine type was INGERSOL RAND. The drilling operations were carried out by EnGeo – Laboratory of Engineering Geology (Geology Department of Patras University).

1) Disturbed samples were obtained using: a) double type core barrel, T6S Craelius, step type with diamonds core bits and hard metal bits and; b) Simple wall core barrel with carbide bit and water interruption (dry sample) (Fig.1).

2) High quality samples (undisturbed samples) have not been obtained due to the type of ground formations (sand and gravels, rock fragments, rock boulders etc.).

The special characteristics of the drilling machine are summarised below.

<table>
<thead>
<tr>
<th>Brand</th>
<th>INGERSOL RAND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling Type</td>
<td>RESKA R30TD</td>
</tr>
<tr>
<td>Purchase Year</td>
<td>1998</td>
</tr>
<tr>
<td>Serial / Engine Number</td>
<td>146/6567773</td>
</tr>
<tr>
<td>Engine Type</td>
<td>DEUTZ F6L 912</td>
</tr>
<tr>
<td>Power / Rpm (rpm)</td>
<td>120/2800 max - 95/2300 oper.</td>
</tr>
<tr>
<td>Water pump</td>
<td>BERTOLINI S130 (Supply 130 lt/min, pressure 50 atm, Hydraulic transmission, 2x3 piston - system)</td>
</tr>
<tr>
<td>Casing diameter ex/in (mm)</td>
<td>180/160, 140/125, 117/104, 98/89</td>
</tr>
</tbody>
</table>
Drilling process carried out in the four LANDSLIDE test sites

The laboratory testing of samples was performed according to Greek norms (E 105 – 86). These tests include:
- Measurement of moisture (w%) (Fig.2)
- Grain size analysis (sieve analysis)
- Particle size analysis (hydrometer method)
- Atterberg limits
- Unit weight (γb kN/m3)

Figure 2: Special preparation of moisture samples. 9-12 June 2015 – Greek test site

9-12 June 2015 – Greek test site
Drilling process carried out in the four LANDSLIDE test sites

Test site 2: Province of Ancona – Italy

The drilling operation was carried out on the 9th and 10th of July by the Tecnosondaggi company of Osimo (Ancona) with continuous core sampling. Because the average depth of the bedrock was individuated six meters below the surface it was decided to make six surveys of ten meters instead of four of fifteen meters as requested by the project protocol. All the core samples were collected in sampling boxes, each of them containing five meters of samples. Because the bedrock depth was unknown before the perforation, to be sure to take the second sample for the geotechnical parameters at the right deep (one meter up the bedrock depth), a thin walled or Shelby sampler was not used, the samples were taken directly from the sampling box, like it was done for the samples taken for the measurement of soil moisture. In fact it was preferred to have a little more disturb in the sample, but to be sure that it was taken at the exact depth. In any case, only the internal part of the core for the geotechnical exams will be used in order to ensure good quality of results. Every sample taken for geotechnical measurement was sealed up with paraffin.

The stratigraphy of the surveys show that the bedrock is covered by few meters of silty and clay eluvial and colluvial deposits with poor geotechnical characteristics. The water table is also individuated few meters below the surface.

The charts of the spread of the soil moisture with the depth shows mainly two different patterns. The first one, more in accordance with the theoretical prevision, shows a gradual increase with the depth until the phreatic surface and after that a new decrease (in fact the bedrock is formed by impermeable clay). The second shows the maximum value of soil moisture in the most superficial layers then a decrease and an increase again near the phreatic surface.

This fact could be explained by lateral variations in the permeability of soil. In the first case the soil is more permeable, and after rain fall, the first layer begins immediately to dry and the water infiltrates the deeper layers. In the second case the soil is less permeable, i.e. it dries only after several days from the last rain fall with the infiltration of water in the deepest layer, like in the first case. In this second case if new rain fall occurs the surface layers becomes saturated again.
Drilling process, 9-10 July 2015 – Italian test site
Drilling process carried out in the four LANDSLIDE test sites

Test site 3: Regional Administration Smolyan – Bulgaria

Landslide “Smolyan Lakes” is located northwest of the town of Smolyan. The length of the landslide is 5.35 km, average width is 1.38 km and the depth of the landslide area is 35-80 m. Its total area is 7.4 sq.km. The Southwest part of the landslide was chosen for the test area of the project, which location is very close to the living area of the town Smolyan and is entirely within the borders of the structural erosion-gravity type relief, typical for landslides in general.

Four drillings with a total length of 75 m. were carried out in the above-mentioned area:

- Drilling S-1 with a depth of 25 m started on 21st August 2015 and completed on 24th August 2015. Due to the rain it was necessary to stop work for two days.
- Drilling S-2 with a depth of 20 m started on 25th August 2015 and completed on 6th August 2015.
- Drilling S-3 with a depth of 8.5 m started on 27th August 2015 and completed on 27th August 2015.
- Drilling S-4 is with a depth of 21.50 m started on 27th August 2015 and completed on 28th August 2015.

Drillings were performed under the direction of two drilling engineers together with constant presence and control of geologists. Each drilling is documented in accordance with the established Bulgarian methodology. Drill core was stored in wooden boxes with the appropriate labels. The description by the geologists was done right after extracting the kernel. There is a complete photo documentation of the extracted kernel. Every drilling is with lithological column.

Geologists selected the necessary samples for analysis, after completing every drill. After completion of each drilling, properly packaged samples with covering letters, were transported to the licensed laboratory EUROTEST-CONTROL in Sofia for tests.

General and specific data for each drilling is contained in built lithological columns M 1: 250. The columns are followed by detailed description of individual drillings.
Drilling process, 21-28 August 2015 – Bulgarian test site
Drilling process carried out in the four LANDSLIDE test sites

Test site 4: Bielsko-Biala District – Poland

The work, including the geological surveys, conducted in Poland in the framework of the LANDSLIDE project were carried out between the 22-31 July 2015 within the test area of the abandoned quarry in Kozy in Bielsko-Biala district, as well as in the laboratory of the Geological Enterprise in Krakow. For the study of the landslide area there were made 3 drilling operations of engineering-geological kind, marked with symbols A-1, A-2 and A-3 of the total drilling surface of 79 m.

According to the work schedule all the drillings were supposed to be of a depth of 20 m, however due to the structure of the ground the final depths of the drillings were modified. The drilling A-1 was reduced to 12 meters when drilling into the rocky ground, whereas the drillings A-2 and A-3 were extended respectively to 29 and 38 meters of depth. All the drillings were made in the upper part of the landslide: A-1 in the central part of the landslide, A-2 in its upper shelf and A-3 in its middle shelf. Laboratory studies included the determination of the physical characteristics of the soil, as well as indication of the depth of the bedrock occurrence. They were conducted with a total number of 79 samples.

On the basis of the conducted research it can be stated that the area covered by the geological-engineering study shows a relatively complex geological structure. Due to the ground origin, type and consistency of existing soil, 2 separate geological and engineering layers exist: Layer I - anthropogenic structures of the dump; Layer II - flysch rocks of the ground.

When performing the tests, during the drilling activities in the A-1, the groundwater was detected at a depth of 3 m, whereas in the other two drillings, water filtrations were observed at the depths of 8.6 and 32.2 m. Based on the results of both archival research and those conducted within the project in question, it can be stated that within the landslide area there is no continuous groundwater level, which is associated with poor permeability of the structure which constructs the dumping ground or the lack of any permeability at all. This situation also favors the formation of periodic swamps occurring after rainfall, especially in the south-western part of the landslide.
Fruitful exchange among Landslide partners, invited guests and European experts in Bulgaria!

The 3rd SC-meeting of the Landslide project took place in Smolyan in Bulgaria on the 25 February 2016. The meeting was hosted by the Bulgarian Landslide partner Regional Administration Smolyan.

In the framework of this meeting, an exchange session took place where the project was honoured by the presence of several guests and experts from outside the partnership. Among others, the two European Landslide experts, Mr. Alessandro Passuto from the Italian National Research Council, also a member of the European Landslide Expert Group and Mr. Mihai Micu from the Institute of Geography, co-chair of the Geomorphological Hazards Working Group and member of the International Association of Geomorphologists.

The objective of this meeting was to start to exchange and share project activities and mutual experience on landslide risk evaluation methods and approaches with actors also outside the project partnership. Interesting discussions took place amongst others in the panel and round table session held in the morning around the topic “Technical and political challenges of data acquisition: key for correct risk evaluation”.

In the afternoon the SC-meeting among SC-members took place to monitor and follow up ongoing activities as well as to plan and organise upcoming activities to be launched. In fact, the next phase to be launched is the pilot phase, where the model and software will be tested and used within the civil protection departments of the territories involved.

In parallel to the SC-meeting a study visit was carried out, for invited guests and experts, to the Bulgarian Landslide test site, Smolyan Lakes, located on the western outskirts of the town of Smolyan. This is the biggest landslide in Bulgaria and it is located at 10 km from Smolyan. It was registered back in 1923 and has a width less than 1 km, a length of 5 km, a depth of 80 m and a speed of 5-25 cm per year. Not the whole landslide makes part of the project test site, only part of it located in the southern part of the landslide area, very close to the living area of Smolyan. The group visited the 4 drillings and the meteorological station located close to the drillings. The whole group also observed the critical parts of the landslide Smolyan Lakes.
LANDSLIDE RISK ASSESSMENT MODEL FOR DISASTER PREVENTION AND MITIGATION (LANDSLIDE)

Co-financed by the EU

Humanitarian Aid and Civil Protection

Press conference: Pierluigi Maponi, Coordinator of the Landslide project talking to the Bulgarian Media
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