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# Two experimental devices to study the 1D and 3D seepage process of water inside natural soils: a Lisimeter and a Physical Model of Slope.

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# Two experimental devices to study the 1D and 3D seepage process of water inside natural soils: a Lisimeter and a Physical Model of Slope.

**Summary**

This technical report describes two experimental devices: a lisimeter and a physical model of slope, developed at Department of Geotechnical Engineering of University of Naples Federico II, to study the effects of the rainfall on the natural slope stability.
It is well know as different types of slope instability are strictly related to significant rain events due to the interaction between the fluid phase and the soil structure. In facts change of the water quantity stored inside the soil can affect the mechanic behaviour of the soil.
In particular the lisimeter has developed to investigate the relationship between the variation of water content and the related change of the idro-mechanical behaviour of the soil. The slope the pysical model can be used to study those factors affecting rain induced flowslide in pyroclastic soils.
The physical model of slope and the lisimeter are presented along with experimental procedures..

**Keywords:** Climate Variability, seepage, lisimeter, artificial slope, expeimental apparatus.

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## 1_Introduction

Owing to exceptional events of rainfall induced flowslides occurred about ten years ago in the Campania Region, Italy, many research activities were promoted to study this kind of slope failure and understand which can be the causes or the particular environment condition inducing soil mobilization. Usually the natural slopes of Campania Region involved in flowslide events are characterized by a bedrock of limestone or carbonaceous and tuffaceous material inclined between 30°-45°, and covered with a layer of pyroclastic soils no thicker than 2 meters. These soils have been deposited during eruptions of Vesuvius Vulcan and Campi Flegrei volcanic apparatus occurred in the last tens thousand years. They are non plastic silty sands with high porosity (ranging between 60-80) and partially saturated conditions. The high porosity, the lack of electrochemical forces between soil particles and conditions at saturation or near saturation are considered to be the main factors determining soil liquefaction upon failure (Olivares & Picarelli, 2003). As a consequence, the sliding mass accelerates significantly, transforming into a rapid flowslide. The high kinetic energy associated to the soil mass is what mainly causes damages to buildings and infrastructures, along with casualties.

In the last years the increasing of risks has stimulated studies aimed at deeply investigating the slide triggering factors. Some of these factors, such as the layer thickness, the slope inclination and the soil porosity, do not change significantly during a rain event and are typically used to build up susceptible maps of areas where flowslides are likely to be generated.

Other factors, such as soil suction and water content, may vary significantly during a rain event; since a slide trigger is determined by their changes, they are now going to be used, along with the rain itself, in early warning systems.

The above mentioned factors may be investigated either theoretically, by using mathematical models solved through numerical approaches, or experimentally, by reproducing such phenomena in laboratory in quite controlled conditions. This latter approach inspired the development at the Department of Geotechnical Engineering of University of Naples of a physical model to simulate flowslides and a lisimeter to investigate the idraulic and mechanic behaviour of the soils involved in this kind of phenomena. The model is much larger than other ones developed in the past (Olivares & Damiano, 2005) in order to permit extending experimental results directly to site conditions, without dealing with typical troubles related to scaled tests. The aim of the experimental activity carried out on the slope prototype is to measure some physical variables as suction and water content at different depths during rain simulation, and observe the displacement and deformation of soil sample as water content increases. The lisimeter can be used to estimate the water retention curve on a large sample of pyroclastic soils, in enviromental or in quite controlled conditions using.

This technical report describes the two experimental devices in all tehir components and the experimental procedure followed during tests.

## 2_Testing apparatus and other equipment

### 2.1 Physical model of slope

Since the slide velocity represents a crucial matter in the hazard evaluation, the prototype design was conceived to investigate how different factors influence not only the slide triggering but also the slide post-failure behaviour. According to these aims, the core of the physical prototype is made up of two parts supported by a steel frame: the upper one, where the flowslide is generated (Fig. 1, tank A); the lower part, located downstream of the upper one, where the post-failure behaviour may be observed. This in order to identify if the kinematics is that of a slow-dry flowslide or that of a rapid one (Figure 1, tank B). All the wall of the tanks are made of steel sheets welded to the steel section bars of the frame.

The two tanks may also be inclined differently each other (Fig. 2), to make possible studying geometries where the inclination that regulates the slide trigger differs from that governing the post-failure behaviour. Inclination is provided by two couple of hydraulic rams (REXROTH 4WRAE-10 WATT 60-22), pressurized by a plunger (REXROTH IDRAULIC 4WE10 HP32/CG24N9K4). A first couple or rams connects part B to the steel plinth and may incline both parts up to 45° with respect to the horizontal plane; the second couple of rams connects the part A with the part B and may incline the former with respect to the latter. In this way, inclination of the sample may reach 70°, or may be reduced down to 0°, thanks to the particular position at rest of the rams allowing them to be shortened or enlarged. All the movements of the model are servocontrolled by a PLC (programmable logic controller). The slope position is measured by means of inverters setting on the rams as well an accelerometer placed under the tank A.

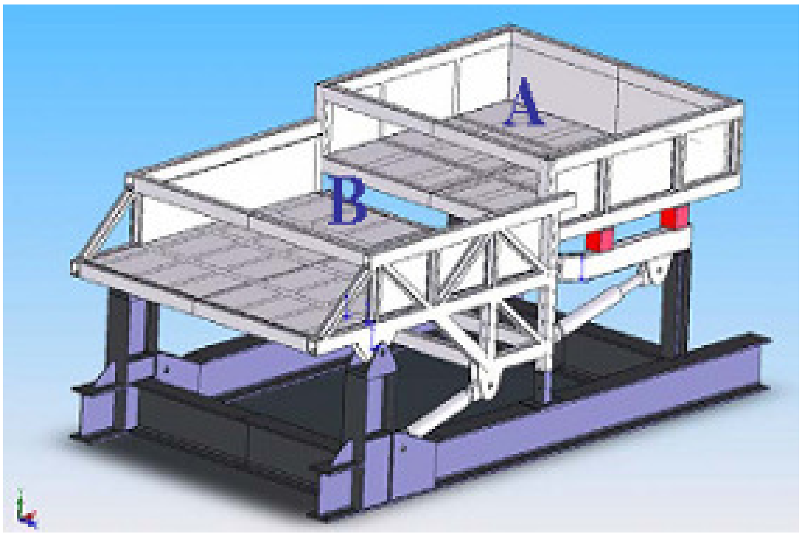


Figure 1. Physical model scheme.

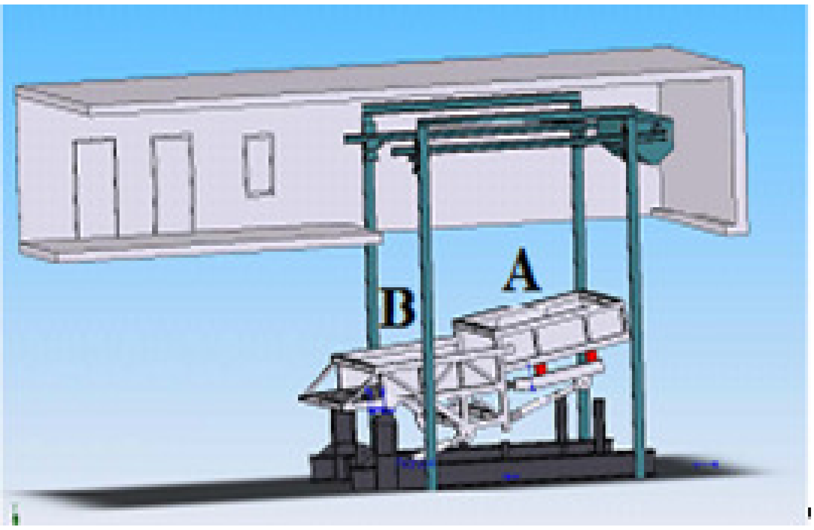


Figure 2. Traveling pluviation system.

Both tanks A and B are 3x3 m in plant. The whole structure has been designed to be loaded by 12 t, so that samples up to 0.7 m thick may be tested.

In the tests carried out up to now the samples have been fully restrained at the lower boundary, where also free drainage has been ensured through a geosintetic sheet. The soil has been glued at the bottom contact (on the base of tank A), in order to make the sliding mechanism fully regulated by the soil friction angle. The bottom of the tank A has been left impervious during the tests.

Downstream of the part B a third tank collects and stores the mud after the slide has occurred (Figg. 3, 4).

## 2.2 Traveling pluviation apparatus and soil treatment

Considering that to reproduce the natural pyroclastic layers the soil sample reconstructed on the model has to be characterized by an high porosity a travelling pluviation apparatus has been placed outside the prototype to make the sample using the air dry deposition technique. In fact, respect to other sample preparation methods the air pluviation allows to reach a good level of uniformity and high porosity value. The pluviation system consists of an hopper moving backward and forward on the tank A to make the sample as a sequence of thin layers. The hopper puts in place the soil on part A (Figg. 3, 4). It has a volume of around 3 $m^3$ and the same width as the part A. The hopper climbs vertically along four tracks. Two couples of electrical engines (Neri motors, T Series three-phase induction motors), are used to regulate the hopper height respect to the required deposition fall. It is possible to drive the two couple separately to tilt the beams supporting the hopper whenever it should be necessary to carry out the pluviation process while the prototype is sloped.

Other two electrical engines move the hopper horizontally above part A along two worm screws; the hopper velocity may be set automatically as well as the start and the end of the hopper run. The maximum velocity is about 10 cm/sec. The hopper produces the pyroclastic fall through the lower opening; to influence the soil density both the fall height and the opening width may be regulated automatically.

The maximum soil quantity carried out by this structure amount to 1.5 ton, nevertheless during deposition process this load is never achieved because of a lower quantity is necessary to form a thin layer of soil. Moreover a greater mass of soil produces aggregates which can affect the uniformity of particles flow; in any case four mechanical shakers are fixed on the lateral walls of the hopper to facilitate the soil fall.

As well as the other mechanical devices, the all couples of electrical engines are synchronized and (servo-)controlled by a PLC (programmable logic controller).

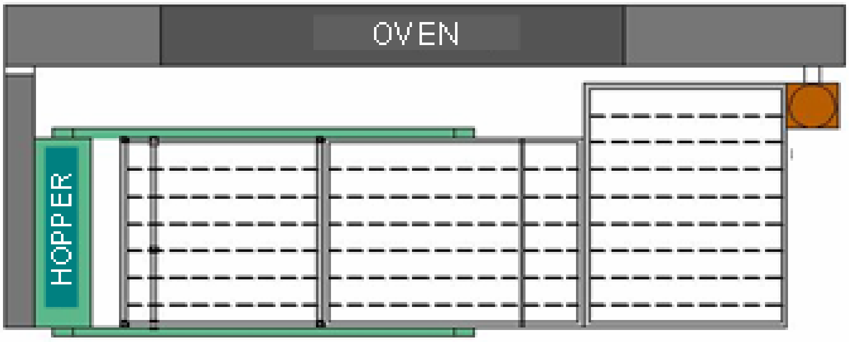


Figure 3. Plan view of conveyer belt around the apparatus.

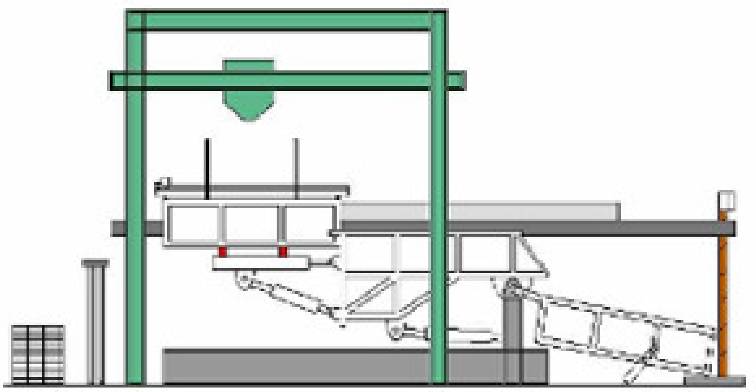

Figure 4. A schematic section of the whole set of apparatus.

To obtain an uniform pyroclastic fall the soil needs to be preliminary disaggregated and dried. The whole deposition system is therefore made of other various components, which are outlined below in the same sequence as they are usually used during sample making procedure:

- a vibrating sieving (Fig. 5), used to disaggregate the soil particles, typically taken together in significant lumps by soil suction;

- a oven 8m long and 0.8m large (Fig. 3, 4);

- a buckets carrier (Fig. 6) used to rise the soil up to oven level;

- a conveyer belt which moves the soil through the oven;

- a second conveyer belt which spreads the soil into the hopper (Fig. 7);

The temperature in the oven is about 150°, not greater to avoid damage to the rubber of the conveyer belt. The time require to dry the soil is about 30 min because the soil layer crossing the oven has a thickness less than 5 cm and a low initial water content.

Figure 5. Mechanical sieve.

Figure 6. Bucket carrier.

Figure 7. The conveyer belt used to spread soil into the hopper.

## 2.3 Rain Simulation system

The rain is reproduced by means of a set of four PNR Full cone nozzles located above the sample at the end of the four arms overhanging the part A inward (Fig. 8). Nozzles have been employed to vaporize water to reduce erosion of the sample surface during the test (actually erosion is reduced by vegetation which protects the soil surface).

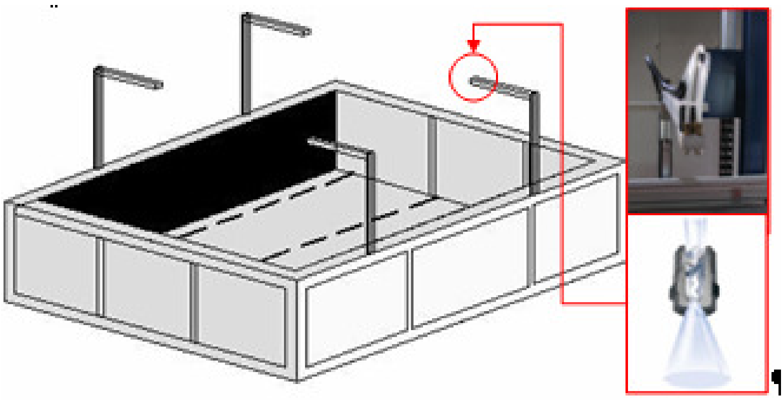

Figure 8. Rain simulation system.

The rain comes out as small drops limited into a cone volume. This cone has origin point at the nozzle orifice and is characterized by a spray angle of 90°. The nozzle sprinkles on a circular area so the soil sample surface cannot be wet uniformly; to cover almost all the sample surface and to avoid the overlap of the drop flows the nozzles have to be placed 80 cm above the soil sample (Fig. 9). It is possible to regulate the nozzles height by moving the horizontal arms along their vertical support. In order to avoid interferences during soil deposition process, each horizontal bar is equipped with a mechanic device which moves it above the tank walls (Fig. 10).

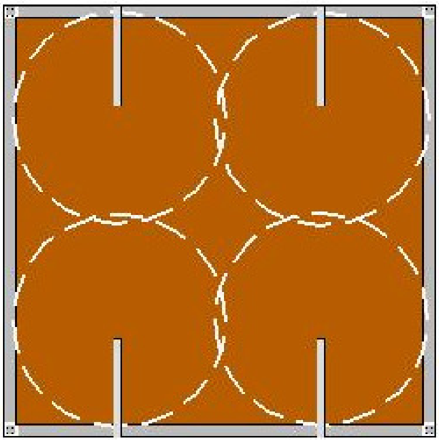

Figure 9. Sample surface covered by rainfall.

Figure 10. Rest position of rain simulation system.

The rain intensity may vary from 20 to 200 mm/h. To cover this wide range three different size nozzles have been installed on each bar as the nozzles capacity is a function not only of the inlet water pressure, but also of nozzle internal design. A drainage system was designed to supply separately the different set of nozzle on the basis of the desired rain intensity. The circuit is made of a main tube connected to three other drainage patterns by means of a set of valves (Fig. 11). By opening one of these valves it is possible supply the related set of nozzles. An hydraulic pump collects the water from a reservoir placed below the slope prototype which has a capacity of 1000 litres. Downstream the pump a pressure transducer measures the water pressure.

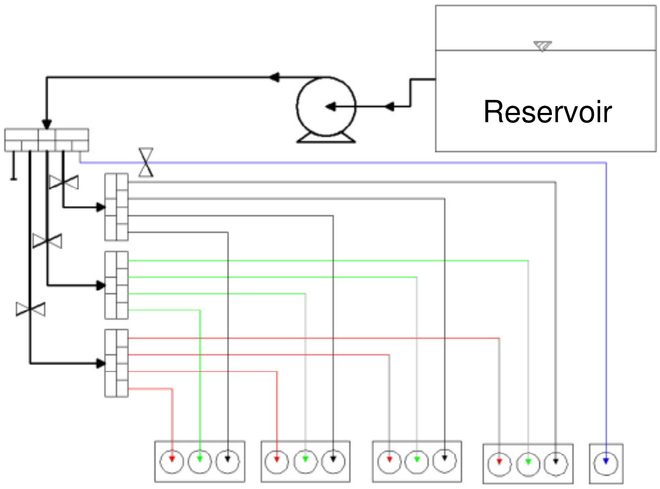


Figure 11. Drain system of rain simulation apparatus.

All the mechanical devices and the drainage system are computer controlled by means of a software compiled in LabWindows CVI. This software allows also to collect pressure transducer measures and choose the rain intensity by setting the water pressure and the set of nozzle to be used.

## 2.4 Measure devices

During a test the typical measurements carried out are:

- changes in weight of the sample;
- surface displacements;
- water content;
- soil suction.

Some of monitoring instruments are part of the physical model and have been designed along with it; other ones are “external”, and consist of devices suitable to monitor the behaviour of a real slope.

The instruments which are part of the model consist of:

-four load cells (Fig. 12), installed as support of part A; each cell measures continuously in time the six reaction force components; as a result, changes in weight of the part A may be obtained; such changes may be used to derive the sample unit weight during the soil deposition, the changes in the water mass stored by the sample during the test (as a result of the rain, seepage processes and run off), the losses of soil mass associated to the occurrence of landslides or limited earth flows. The load cells are MC8 series of AMTI Multi-Component Transducers. This kind of transducer incorporates strain gauges and a precision element to isolate and measure applied forces and moments. It has six outputs corresponding to Fx, Fy, Fz, Mx, My and Mz calculated respect to a Cartesian coordinate system integral with the cell useful to calculate the vertical load independent of slope configuration. The standard vertical load capacity is 9 ton, while the horizontal load capacity is half of the vertical rating. The moment sensor ranges are 460 kg*m for Mz, and 920 kg*m for Mx and My components. These sensors have a non linearity of ±0.2% of full scale output. AMTI's DSA-6 six-channel, high gain, strain gauge amplifier is used to process the signals and provide output suitable for A/D converter and digital computer. The same software used to control the rain system was implemented to collect the measurements of load cells and accelerometer setting under the tank A.

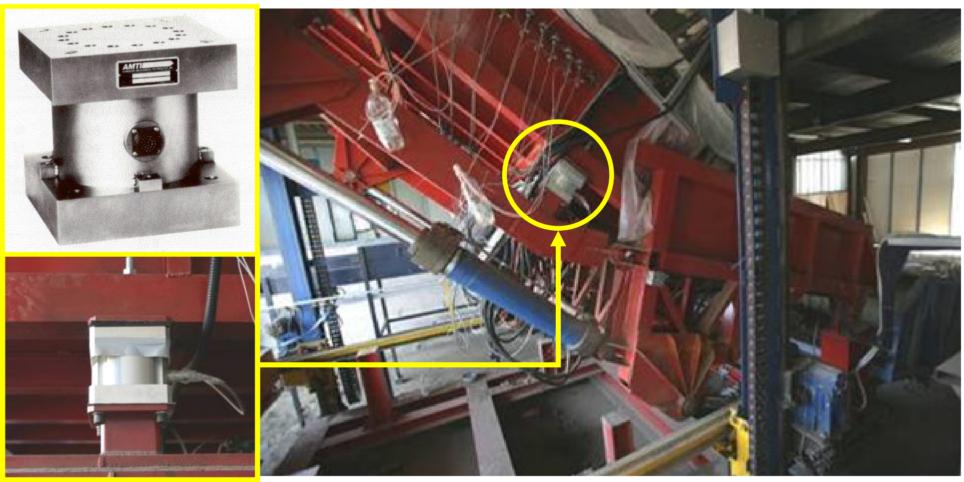

Figure 12. A detail of the load cell..

-A 2D digital laser scanner device (MEL, M2D Laser scanner CCD digital), that acquire with the triangulation technique the position of the sample surface. This Laser has a depth of scanning of few centimetres; the scanner is moved parallel to the sample surface by a mechanical (robotized) system (Figs. 13, 14), to acquire the whole soil sample surface or part of it at different time.

The moving system is made of a metal frame fixed on the tank A border, and two electrical engines to move the scanner along the whole sample surface: the laser motion is direct along two perpendicular direction and can have different velocities. The scanner velocity can be regulated to acquire the whole shape of sample surface in 1 min at least. The laser acquires a strip 100 mm long with a frequency greater of 50 sample per second up to a dept of measurement of 200 mm. The accuracy depends on the velocity of the laser movement and has a maximum value of ±0,5 mm. Measure accuracy is so fully satisfactory, while the time period needed to scan the entire sample surface is significant (about six minutes), and makes such technique only suitable to characterize the pre-failure stages.

This equipment can be used also when rain simulation system is working. Nevertheless it would be better to stop rain for few minutes to reduce noise during acquisition.

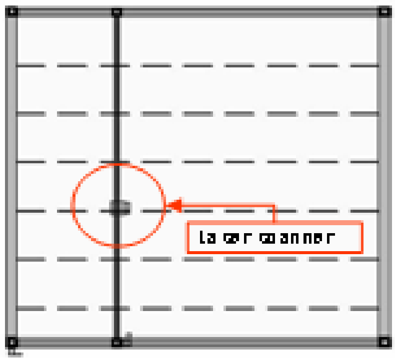


Figure 13. Plan view of the laser scanner supported by the moving system.

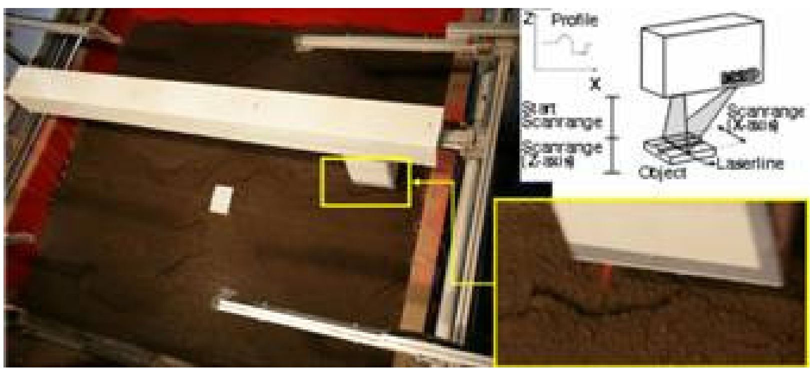


Figure 14. Laser scanner apparatus.

-A Particle Image Velocimetry (P.I.V.) technique based on the interpretation of images taken by a video camera (Basler A404K), pointing normally to the sample surface at a distance of about three meters (Fig. 15); results are in terms of sequence of two-dimensional velocity fields; these measures are characterized by a good time resolution (up to 25 images per second may be acquired and interpreted) but by a poor accuracy (approximately 20mm); however the P.I.V. technique integrates to extent the laser scanner technique: it is suitable to monitor the failure and post-failure stages, when the occurrence of rapid movements requires high time resolution and the significance of displacements makes poor accuracy acceptable.

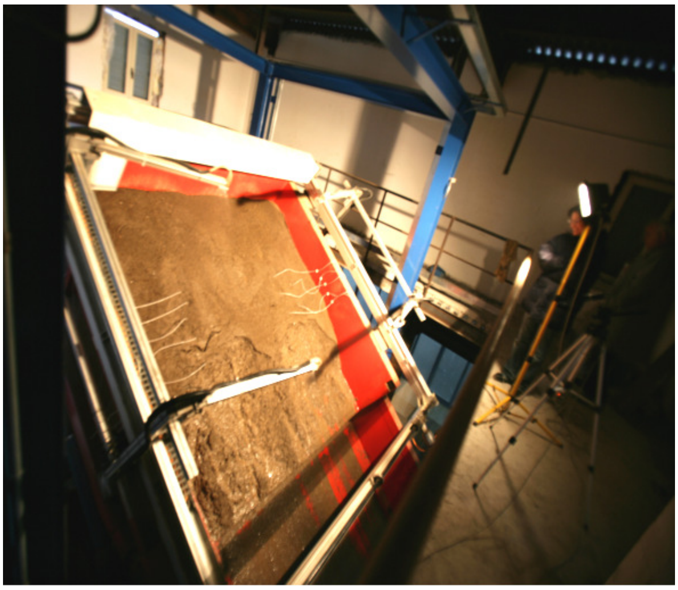

Figure 15. P.I.V. apparatus.

All the equipments or devices used allow to employ not intrusive measure techniques. They are remote controlled by computer or PLC (programmable logic controller) using software compiled on purpose to manage these apparatus.

The external instruments are used to characterize the sample hydraulic behaviour; they consist of N. 20 small tip Soil Moisture tensiometers and TDR probes to measure soil suction and water content respectively. As the flowslide involved almost the whole thickness of soil layer these instruments are installed during the deposition process at three or four different depths to study the water flow trough the sample. Pressure transducers supply to collect and to stored suction data in a Campbell data logger (CR1000) along with the TDR measurements.

## 3_ Experimental procedures

The activity carried out until now on the slope prototype regards experimental tests aimed at understanding trigger of flowslide in pyroclastic soil. Each test is performed simulating a rainfall with constant intensity above the soil sample, inclined respect to the horizontal plane, up to reach failure.

The soil tested is a volcanic ash, made of non plastic silty sand with gravel (see fig. 16); it is the same soil involved in a significant rapid flowslide of 33000 m3 occurred on 4th March, 2005 and affected a slope inclined of 37° close to the Nocera town (Salerno).

The soil samples have been reconstructed using the travelling pluviation apparatus mentioned above. The deposition phase requires at least one or two days to be performed. Before start with pluviation, it is necessary to let soil becomes sufficiently air dry for sieving. In fact aggregation of wet soil may obstruct the mechanical sieve. Moreover to handle dry soil allows to reduce the time required for the oven dry stage and so the time necessary to put in place the whole sample.

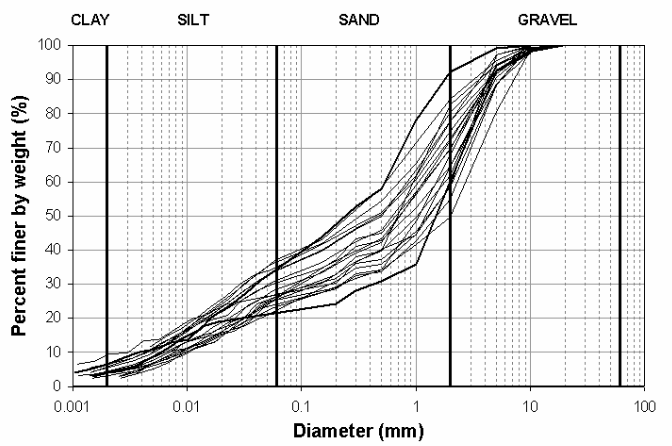


Figure 16. Soil grading.

Samples was reconstructed as a sequence of thin oven dried soil layers. Usually the deposition was interrupted after that sample thickness of about 10÷15 cm has been formed, this to allow to set tensiometers and TDR probes. At the same time the rain system is activated to increase a little the soil humidity in order to facilitate the raise of water content before test starts.

Once sample has been done, it has been wetted during about a week, to increase suction up to the desired value. This because a lower suction is more representative of situ conditions related to flowslide risks, but also because a high suction may cause desaturation of tensiometers. Moreover a decrease of soil suction reduces the time required to reach failure.

It is necessary to wet the sample switching on the rain system many times for few minutes. In this way it is possible to give the needed quantity of water to the soil reducing the settlement of the sample.

Up to now in the tests carried out the samples have been characterized by a thickness of 40 cm and with soil porosity ranging between 60% and 70%. The samples have been put in place taking the part A horizontally. The sample has been inclined only before the start of the test. Inclinations ranging between 32° and 40° have been adopted for the samples (part A). Part B has instead been slightly inclined (10°), in order to make more easy to identify the post-failure behaviour, by maximizing differences in the time needed to cover the trench between a rapid flowslide and a slow-dry one.

The series of experimental tests have been carried out keeping constant rain history (rain intensity = 30 mm/h) and, while the initial state in terms of soil porosity and soil suction, along with the sample inclination, have been varied.

## 4_Lisimeter

The lisimeter is a device useful to study the hydro-geological cycle measuring its components: seepage, evapotranspiration, run-off, etc.... It consists of a thank which contains a undisturbed or reconstructed large soil sample, equipped with different sensors, each able to measure specific physical variables.

The experimentation carried out with the lisimeter can be performed in laboratory under controlled conditions, or directly in situ measuring also the environmental conditions.

This type of apparatus was developed to study the water balance and the evapotraspiration of the soil under cultivations. In the last years these devices have been employed in geotechnical applications to estimate also the water retention properties of the soils.

The lisimeter developed at University of Naples Federico II consists of a tank in nautical multi-stratum plywood which rests on frame made of aluminium square section bars 40x40x5 mm (see Fig. 17). The tank has a square area of 1.25x1.25 $m^2$, and a depth of 0.80 m. It may hold a soil sample representative of those stratigraphy indicated in literature as soil layers involved in flowslide events.

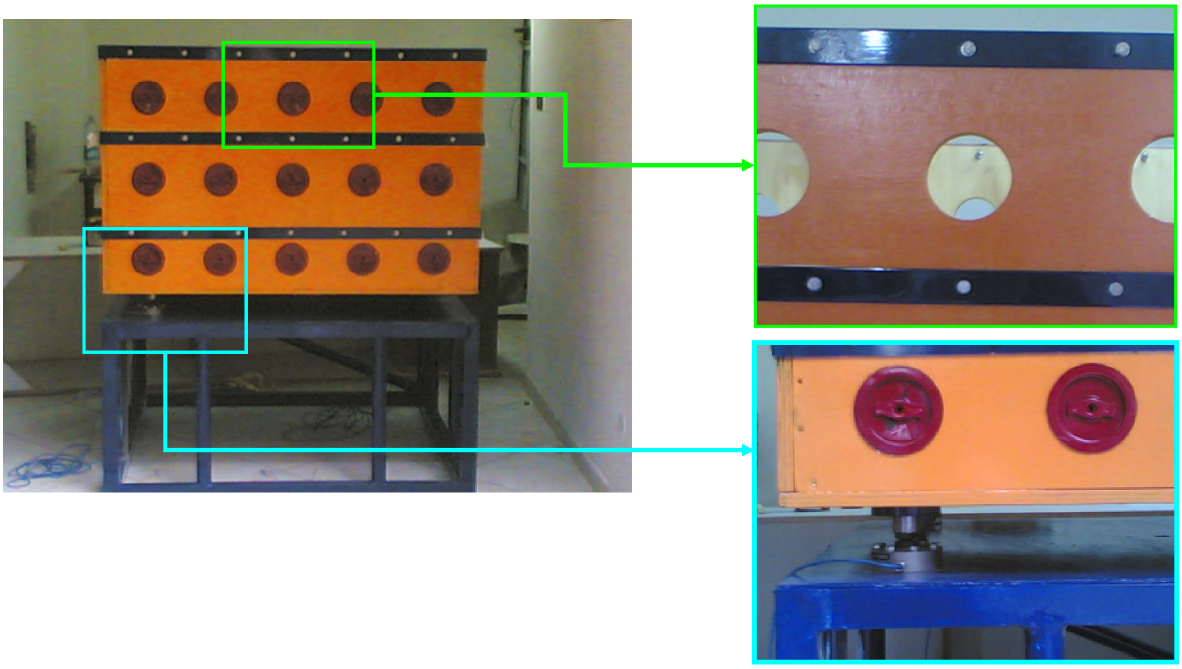

Figure 17. Lisimeter.

On the lateral tank walls there are circular openings to put in place sensors inside the sample at different depths. The holes have a diameter of 16 cm to insert sensors with different size as tensiometer or TDR probes. After sensor have been placed, the holes are closed by means of plugs with a rubber seal to avoid loss of soil and water. The sensor cable pass through an apposite slot formed in the plug.

There are other holes on the bottom of the tank. They are covered with a geosynthetic cloth to allow water drainage, but at the same time to avoid loss of material.

Between the tank and the aluminium structure there are N. 3 load cells to measure the weight variation of the soil sample due to variation of soil water content. Their vertical load capacity is of 1 ton. The cells rest on a steel plate 1 cm thick to assure an almost uniform distribution of the weight among the cells.

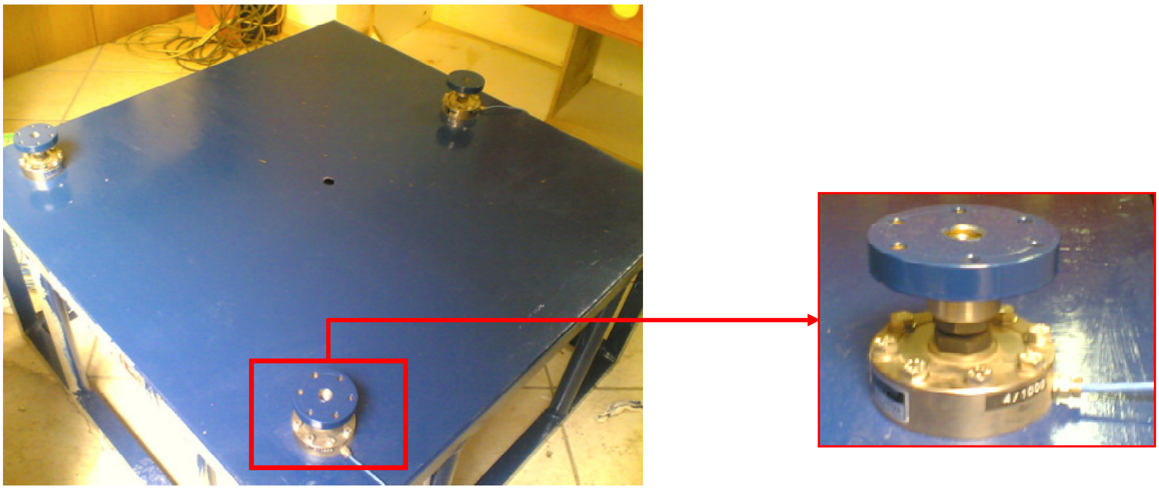

Figure 18. Load cells.

The technique of time domain reflectometry (TDR) is used to measure indirectly the water content inside the sample at different level (Fig 19).

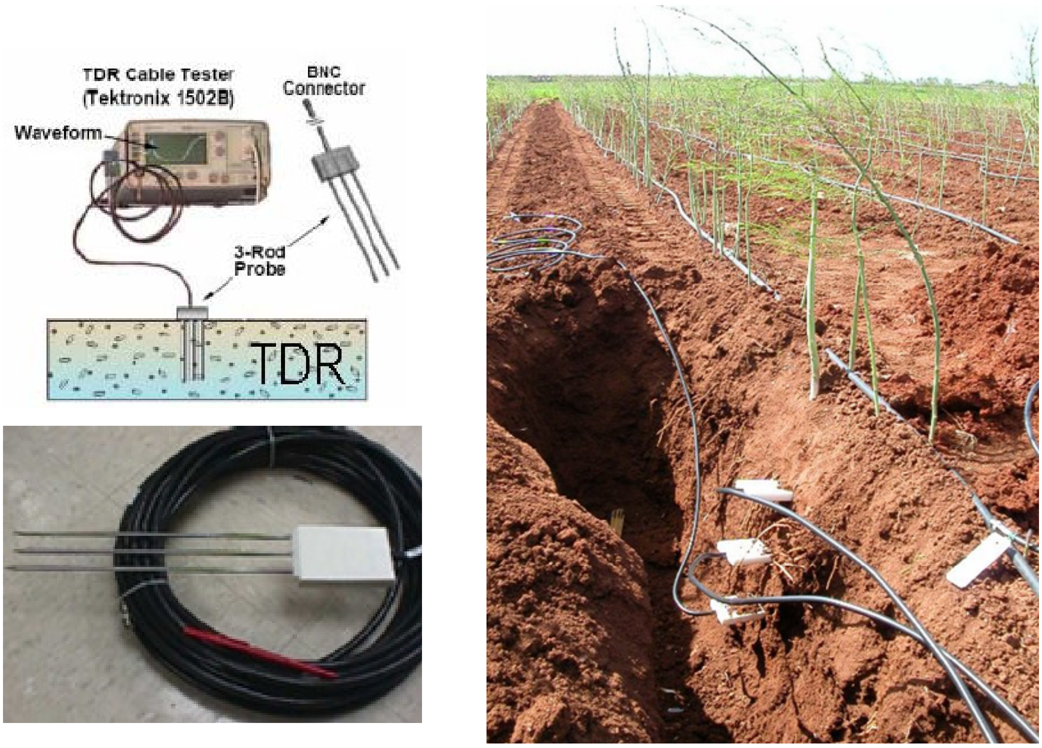


Figure 19. TDR apparatus.

This technique allows to accurately determine the permittivity (dielectric constant) of a material from wave propagation. As indicated by many authors, first of all Hoekstra and Delaney (1974) and Topp et al. (1980), there is a strong relationship between the permittivity of a soil and its water content, whereas the permittivity is independent of soil density, texture, temperature, and salt content.

In all, the lisimeter is equipped with N. 8 TDR 3-rod probes 30 cm long connected to a time domain reflectometry.

As to determine the retention properties of a soil it is necessary to find out the relationship between the soil water content and the water potential, the lisimiter was also equipped with tensiometer and thermal conductivity sensors to measure matrix suction (defined as the difference between air pressure $u_a$ and water pressure $u_w$).

There are N. 13 Soil Moisture small tip tensiometers (see fig. 20), able to measure negative water pressure inside the soil. This type of tensiometer consists of a rigid plastic body tube filled with water and connected to a h.a.e.v. (high air entry value) porous stone, by means of a flexible and thin plastic tube.

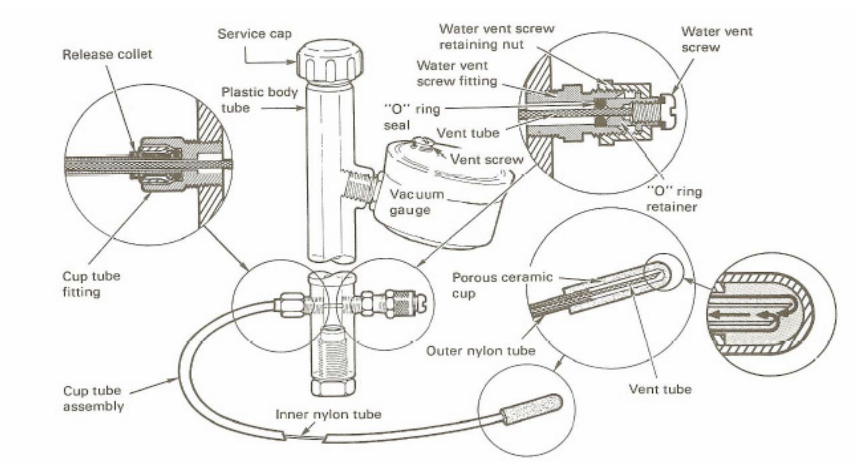


Figure 20. Soil Moisture small tip tensiometer.

Once the all parts of the instrument are totally saturated, the porous stone is put inside the soil. Here there is a tendency of the meniscus water of the porous stone to equilibrate the pressure of the soil pore water. The time necessary to reach the equilibrium depends of the soil pore water pressure value.

The water pressure in the tensiometer is measured by means a pressure transducers connected to the water reservoir inside the tensiometer. A datalogger (CR1000, Campbell Scientific) collects and stores the data. As in the soil the air pressure is zero, the suction is directly equal to water pressure $u_w$. The tesiometers can measure suction between 0 up to approximately 80 kPa, and needs to be saturated especially when suction reaches values near to the device capacity.

To read higher values of suction 229-L Campbell Scientific thermal conductivity sensors are used. They consist of a thermocouple and a heating element integrated in a needle. The needle was plunged into a high conductivity epoxy resin, and then incorporated into a porous ceramic element. To calculate soil water matrix potential, a current excitation module applies a 50 mA current to the 229's heating element, and the 229 thermocouple measures the temperature rise. As the thermal conductivity of the porous ceramic element is related to the amount of water in the porous ceramic matrix, the magnitude of the temperature rise varies as the surrounding soil wets and dries. After a calibration of the sensor in the soil type in which it will reside, it is possible to obtain a relationship between the measures of the temperature rise and the suction.

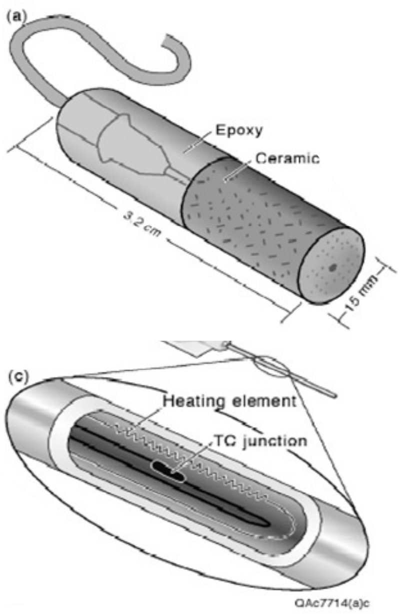


Figure 21. 229-L Campbell Scientific thermal conductivity sensors.

The 229-L Water Matrix Potential Sensor measures soil water potential from 0.1 to 10 bars, and, unlike tensiometer, it does not need periodic maintenance.

There are N. 5 229 sensors available for the lisimeter. These sensor are connected to the same datalogger which collects the measure of tensiometer and TDR system.

A weather station is placed close to the lisimeter to measure the environmental variables: rain, atmospheric pressure, relative humidity, temperature, and velocity and wind direction. This to correlate the variation of soil humidity to the change of environmental conditions. The weather station consists of: a rain gauge, a temperature and relative humidity sensor, barometer and an anemometer.

## Conclusion

The aim of these experimental activities is to obtain data useful to study the effect of the rain events respect to the environmental hazards and to validate the efficacy of environmental monitoring system.

All the set of data obtained from the experiments performed on the lisimeter and the physical model of slope, will be employed to validate the results of numerical analysis carried out by using the specific code. These code are been chose as suitable to study flowslide phenomena.

In particular the slope apparatus may be used to study the influence of the main factors affecting the trigger of such phenomena. As well tensiometers and TDR measures along with the weather station measures may be used to characterize the hydraulic behaviour of soil and to estimate the time after which the landslide may trigger.