GEOSTRU GEOROCK 2D

1 GeoRock

GeoRock is a software made by GeoStru for the 2D simulation of rockfalls using Lumped Mass and C.R.S.P. models.

Computation models

For the **Lumped Mass** model, the computation assumptions are:

- plan outline
- slope profile similar to a broken line consisting of straight line segments
- point boulder
- neglectable air resistance

The **CRSP** model (Colorado Rockfall Simulation Program) has been developed by Pfeiffer and Bowen (1989) with the purpose of modeling the falling motion of boulders having the shape of spheres, cylinders or discs, with circular cross section in the vertical plane of the movement. The reliability of the model was verified by comparisons between numerical results and those obtained from in situ tests.

Interface with other GeoStru software

The software is interfaced with other GeoStru programs:

- TriSpace for the automatic generation of sections from an xyz plane or from raster images
- GeoStru SRTM for the automatic generation of topographical sections starting from Google Maps
- GeoStru Maps, the new online App from GeoStru, that allows you to create topographic sections in a very simple way

Works of intervention

The software allows the insertion of energy dissipators along the profile:

- rigid barriers
- elastic barriers
- backfills
- ditches

After the simulation the designer has the data needed to proceed to their sizing.

Computation

The program performs the computation according to the statistical and deterministic approach, the user can choose to make a point launch or define a launch area. The user is given the option to choose the shape of the boulder:

- sphere
- cylinder
- disk

Output

GeoRock returns information about the energy, velocity, time of flight and height of the parabola at any point of a generic trajectory of the boulder.
After the computation is given the opportunity to view, print or copy the energy diagrams, trajectories or energy histograms, diagrams that can be managed individually or as a whole (using the command "*Envelope*").

1.1 File

Import file from other GeoStru software

Imports the profile of the slope from a file generated by other GeoStru programs.
From TriSpace software, the section created can be saved as (*.sec) and imported in GeoRock after selecting the file extension from the specific command.
From Geostru Maps App, once identified the area of interest on the work area a sequence of points must be inserted with the mouse, then must be selected the command "*Find Elevation*" and subsequently the command "*Section*". The section will be displayed on a Cartesian plane and can be created with a (*.sec) file extension and then imported into GeoRock.

Import Excel file

Imports data that define the profile of the slope from a *.xls file The file must be structured as follows:

- first column - serial number of the vertices of the slope starting from the number one
- second column - x-coordinate of the vertex
- third column - y-coordinate of the vertex

Import DXF file

Imports the data of the topographic profile from a *.dxf file. In the *.dxf file the slope must be defined by an open polyline in the *Layer 0*.

1.2 Home

General Data

Enter the description of the work. The user can choose whether to include into the output report the description of the work using the specific checkbox.
Is is also possible to specify the area of intervention that will be displayed on a map. There are two possibilities to locate the area: Enter the WGS 84 coordinates or indicate the country and the city.

Find on map

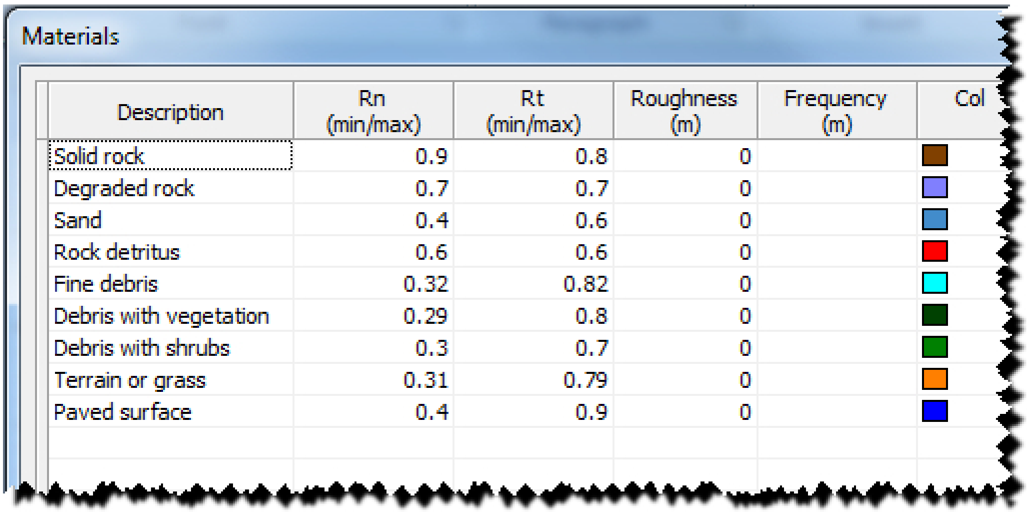
The command connects GeoRock to the free application ***Geostru Maps*** that allows you to:

- find the elevations of assigned points
- plot longitudinal sections
- plot spot height plans

To create a 2D section you can proceed in two ways - assign points or create a polyline, (for the polyline confirm with a right click), search for the elevations using the command "*Find Elevation*" (wait..), run the command "*Section*".
After creating the 2D section with the above procedures, the section should be saved with the command "*Export*" in (*.sec) format. The section can be imported in GeoRock2D using the command "*Import file from other GeoStru software*" from the File menu.

Materials

The program has a database of materials that can be used to characterize each section of the slope.
For each material are defined two restitution coefficients (normal and tangential) the roughness, the frequency and the color.
The tangential coefficient determines the reduction of the velocity component parallel to the profile section during the impact. The normal coefficient is a measure of the velocity change, normal to the profile before and after the impact.



Materials

Description	Rn (min/max)	Rt (min/max)	Roughness (m)	Frequency (m)	Col
Solid rock	0.9	0.8	0		
Degraded rock	0.7	0.7	0		
Sand	0.4	0.6	0		
Rock detritus	0.6	0.6	0		
Fine debris	0.32	0.82	0		
Debris with vegetation	0.29	0.8	0		
Debris with shrubs	0.3	0.7	0		
Terrain or grass	0.31	0.79	0		
Paved surface	0.4	0.9	0		

Obviously, while the vegetation influences the tangential coefficient, the stiffness of the material influence the normal coefficient.

The presence of vegetation with a height exceeding 1 m makes it difficult to determine the coefficients as its presence for the boulders that collapse for first can produce a behavior very close to that of a not very rigid material, but the boulders already collapsed alter the behavior of the boulders that come off after the first ones. The values suggested by the literature are not very uniform, so their validity should always be confirmed by practical applications on real cases.

The roughness of the surface (in m) is the maximum roughness/asperity of the section perpendicular to the slope in a range equal to the radius of the boulder. The roughness defines, in essence, the actual inclination of the slope in the point where impacts the boulder.

The frequency, expressed in meters, defines the interval associated with the i-th slope segment where the roughness periodically assumes the same value.

The *Materials* table is user-editable, so the user can assign any value to the normal and tangential restitution coefficients (R_n, R_t), to the roughness and also the user can associate a color to the material.

The user can customize the database by adding other materials to those already present or edit existing ones. It can also be assigned a color to a single segment of the profile: select the color with left click, with the mouse button pressed drag the selected color on the segment in the workspace.

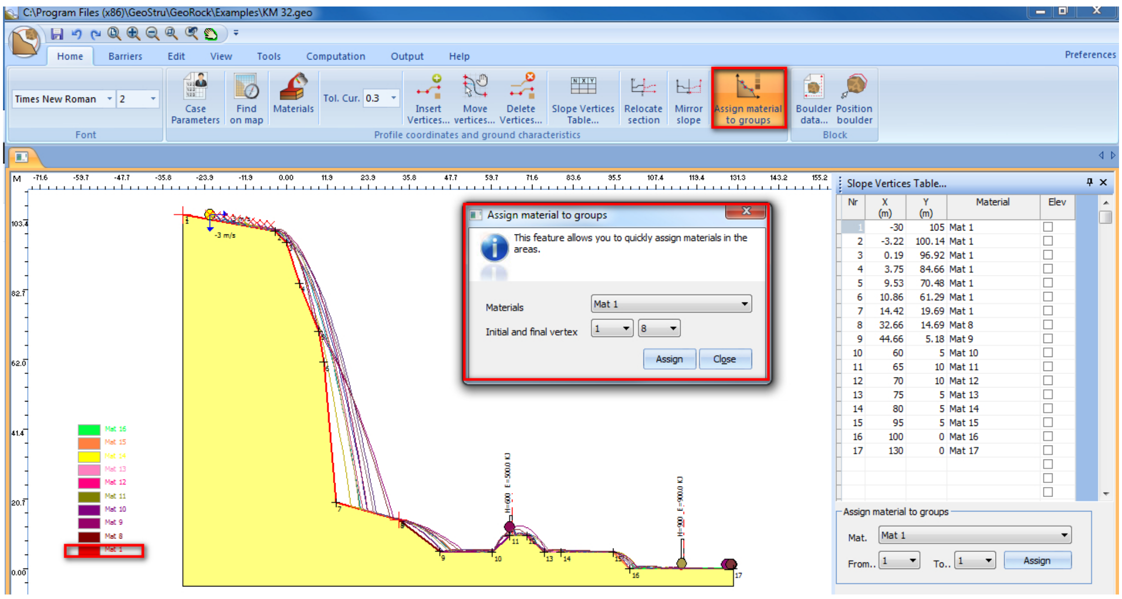
Any changes made with the above operation will update automatically the *Slope Vertices Table*.

To deselect a command click again on the command or press the ESC key.

Slope vertices table

Selecting this command, on the right side of the work area you will see a table where you can change the geometric points that define the vertices of the profile.
Each vertex can be represented with its elevation, its partial distance and progressive distance selecting the corresponding checkbox "*Elev*". The program automatically updates the changes and with a right click the user can choose the option "*Elev. all*" to view the elevations of all vertices.
All data presented in the table can be copied or pasted using the commands "*Copy*" and "*Paste*" that can be selected from the drop-down menu activated with a right click.

This feature allows the user to quickly assign a material to areas of the profile, each area is defined by two vertices: the initial and final vertex.
To keep the change, it must confirmed with the "*Assign*" button. The last coordinate in the table doesn't need to be assigned. The command can also be run from the "*Slope vertices table*".



Boulder specific weight

Unit weight of the material constituting the boulder

Elasticity modulus

Elasticity modulus of the boulder

Initial x axis velocity [m/s]

X-component of the departure velocity; positive from left to the right

Initial y axis velocity [m/s]

Y-component of the departure velocity; positive from bottom up

Terminal limit velocity [m/s]

Value of the velocity reached by the boulder, at which the boulder is considered practically stationary and, therefore, the calculation is stopped

Shot area start abscissa [m]

Enter the value of the x-axis corresponding to the start position of the boulder

Shot area start ordinate [m]

Enter the value of the x-axis corresponding to the start position of the boulder

Throw step [m]

The analysis on multiple launches is performed by varying the position of the boulder starting from the initial position with step assigned

Number of trajectories

Enter the number of trajectories that you want to calculate from the initial position of the boulder

Elevation for boulder position

Enabling this option, the initial position of the boulder is shown together with the elevations

Deterministic analysis

Choosing the deterministic analysis the roughness at the point of impact remains constant

Statistical analysis

The statistical analysis differs from the deterministic analysis by the value assumed by the roughness. For this type of analysis the roughness is given random values

1.3 Barriers

Barrier types 7

In the presence of one or more barrier types, the analysis of the boulder in fall is conditioned by the absorption energy of the intercepted barriers. When the boulder impacts on the barrier with an energy lower than the absorption energy of the barrier, the boulder is blocked. Otherwise the boulder follows its trajectory regardless of the presence of the work.

Barriers inserted

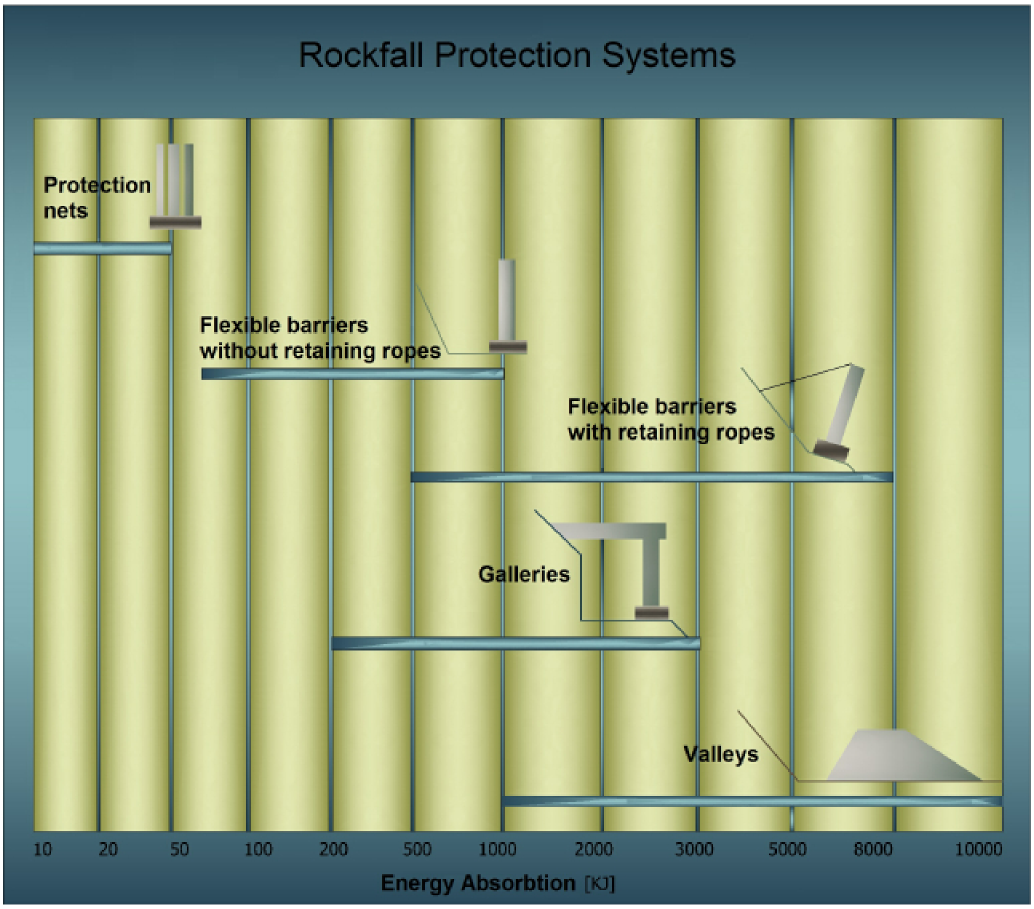
The command displays a table that shows the summary of the inserted barriers: position relative to the reference system and type.

Geoapp Barriers

By clicking on the Geoapp 35 window many news on online calculations.

1.3.1 Rockfall Barriers

The rockfall systems are protection systems having the aim of intercepting and stopping the trajectory of the rock blocks before they can damage the structures to be protected.
The barrier must have the geometrical and mechanical characteristics such as to absorb the kinetic energy and impact of the blocks themselves.
An example of a classification of these systems on the basis of the power of energy absorption is shown in the picture below.



Rockfall barriers can be classified into rigid or flexible, the second ones can be put in place, with or without retaining ropes.
The systems with limited deformability "*rigid*" are designed to stop the boulder in reduced spaces.
The systems which are highly deformable "*flexible*" are designed to dissipate large quantities of energy through a work both in plastic and elastic field.
The proper functioning of a barrier depends significantly on the sizing of the structure components. The main elements are the nets that constitute the main interception structure of the blocks, that, when deforming, dissipate the kinetic energy of the impact.
The value of the dissipated energy can be calculated using the following relationship:

where:

M elasticity modulus

A_f [cm^2] area of the section of the ropes
D_f [cm] diameter of the ropes
A_l [cm] maximum elongation of the ropes

$$A_l = \left[\frac{a_p}{100}\right] \cdot L$$

a_p [%] percentage elongation of the rope, generally equal to 8
L [cm] total length of a rope;
N_f number of ropes involved in the impact

The energy dissipator is a loop of steel wire rope closed by a brake element. When the boulder impacts against the net, the loop tends to slide inside the brake element, dissipating by friction a fraction of the kinetic energy of the impacting boulder. They come into operation when the absorption capacity of the net is exhausted.
The energy dispersed by the dissipators can be calculated using the expression below:

$$E_f = \frac{E_{c\max} - E_d}{L_c \cdot N_d} \, [\text{kgcm}]$$

where:

E_{cmax}-E_d fraction of the kinetic energy not dissipated by the deformation of the net
L_c length of the loop
N_d number of dissipators that come into operation

The *posts* are needed to maintain deployed nets, their static function is indispensable to the functioning of the barrier, it can happen that the boulder impacts with one of the posts that support the nets, and one must verify the amount of energy dissipated in the impact and the need to predispose anchors.
The dissipated kinetic energy is given by:

with

$$F = Mra \cdot \frac{S_a}{H} \text{ [kg]}$$

that represents the maximum load absorbed by the post in the elastic phase

M_{ra} [cm^3]	Modulus of steel strength
S_a [kg/cm^2]	Steel tensile strength
H [cm]	Height above ground level of the post
M_a [kg/cm^2]	Steel elasticity modulus
J_a [cm^4]	Steel moment of inertia

The corresponding maximum deformation of the steel is given by:

$$D_{\max} = F \cdot \left[\frac{H^3}{3 \cdot M_a \cdot J_a} \right] \text{[cm]}$$

Assuming that the deformation of the posts remains in the elastic phase, the kinetic energy absorbed by the anchors will be given by:

$$E_{da} = \left[\frac{0{,}5 \cdot M_f \cdot A_f \cdot D_{ef}^{\;2}}{H} \right] \cdot N_a \text{ [kgcm]}$$

where:

$$D_{ef} = \frac{D_{\max}}{\cos^2 \theta} \text{[cm]}$$

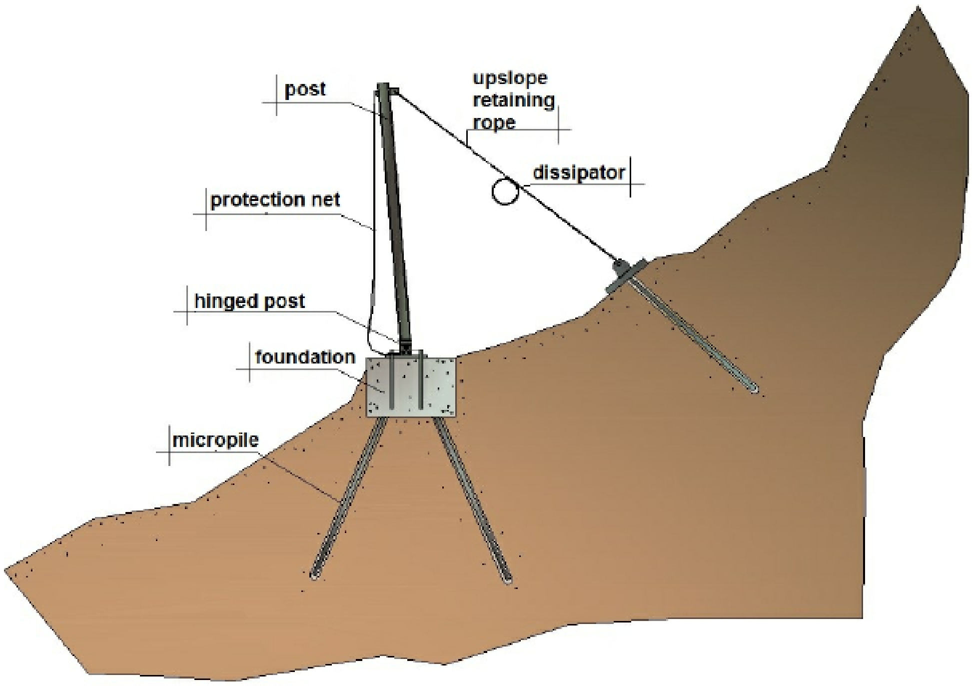
is the elongation of the rope relative to the maximum elastic deformation of the post

M_f [kg/cm^2]	Elasticity modulus of the rope
θ [°]	angle between the anchor and the post
N_a	number of stressed anchors

If is taken into account the maximum deformation that can be absorbed by the ropes we get:

represents the maximum elongation supported by the steel rope

Al_{max} [%] maximum percentage elongation of the rope
L_t [cm] total length of the rope



To verify the performance capabilities of net rockfall barriers are conducted impact tests (crash test). The normative ETAG 027 classifies rockfall barriers in eight different energy classes and for each of them there are two different energy levels.
The energy level of a rockfall barrier is defined as the kinetic energy of a homogeneous and regular boulder that impacts the net of the considered barrier.

- Energy level SEL (*Service Energy Level*) - the SEL test indicates the ability of the barrier to cope a consecutive rock fall events in a in rapid succession.

  The barrier at this energy level must completely stop the boulder in the course of two successive impacts, must be guaranteed during the test some specific standards that we are going to list below.
  The rockfall barrier passes the test for SEL if it meets the following conditions:

  1° SEL launch valid if

  1. The boulder is stopped by the barrier.
  2. There are no breaks in the connection components (that remain connected to the foundations) in the posts and ropes. Breaking means the complete separation of the structure into two distinct parts. The mesh opening of

the net can not exceed two times the initial size of the mesh.
3. The residual height of the barrier after the test (without removing the boulder) is greater than or equal to 70% of nominal height.
4. The boulder does not touch the ground until the barrier has reached the maximum elongation during the test.

2° SEL launch valid if
1. The boulder is stopped by the barrier.
2. The boulder does not touch the ground until the barrier has reached the maximum elongation during the test.

No maintenance is allowed between the first and second SEL launch. The impact energy of SEL level is equal to one third of that of the MEL level, described below.

- Energy level MEL (*Maximum Energy Level*), maximum energy interception guaranteed by the barrier, it must be performed an impact test during which the barrier must demonstrate to stop the boulder and meet the following conditions:

1. The boulder does not touch the ground until the barrier has reached the maximum elongation during the test.
2. The residual height of the barrier must be measured and reported according to the following classification:

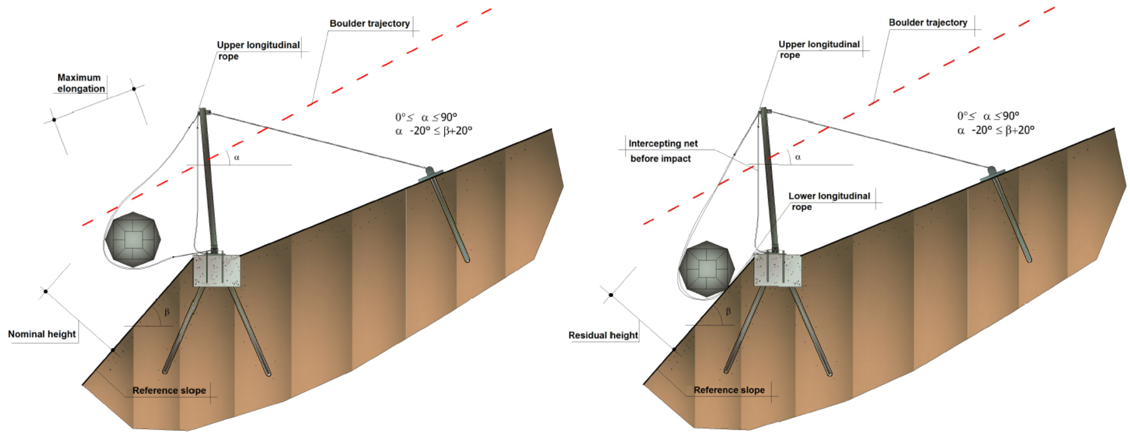
   a. Category A: residual height ≥ 50% nominal height
   b. Category B: 30% of the nominal height < residual height < 50% nominal height
   c. Category C: residual height ≤ 30% nominal height

3. The maximum elongation of the barrier during the test must be measured and declared.
4. Must be drawn up a detailed description of the damage to the barrier after the impact test ended.

In addition to the classification categories as a function of measured residual height, the rockfall barriers are classified according to the levels of SEL and MEL energy that are shown in the following table.

Energy level	0	1	2	3	4	5	6	7	8
SEL (kJ)	-	85	170	330	500	660	1000	1500	>1500
MEL (kJ)≥ (grater)	100	250	500	1000	1500	2000	3000	4500	>4500

The following two figures show the standards to which reference was made in describing the tests prescribed by the standard ETAG 027.



Actions on the foundations

The energy absorbed by the posts, by the dissipating elements and by the upwind system generates efforts on the ground that must be countered by appropriate foundation systems of the posts and upstream and downstream anchors. ETAG 027 standard requires that during the test the soliciting force on the foundation system must be measured throughout the period of impact, so it will be possible to produce a document that describes the trend of the soliciting force as a function of time.
The measuring instruments may be load cells which provide a series of readings per second, but the dimensioning of the foundation is carried out not only as a function of the loads transmitted but also as a function of the geotechnical properties of the site. As a precautionary measure would be appropriate to refer always to the worse configuration.

1.4 View

The most common method to change the views is using the many zoom options of the program, which increase and decrease the size of the image displayed in the drawing area.

Window Zoom

Using Window Zoom you can quickly zoom approaching an area by specifying the angles that define it. The region specified by the selected angles is centered in the new view in case it doesn't exactly match the aspect ratio of the zoomed window. The command can also be activated from the Standard toolbar.

Dynamic Zoom

Zooms interactively using an extension of the drawing. During the dynamic zoom the cursor turns into a magnifying glass with the plus (+) and minus (-) signs. While holding down the select button at the center point of the window and moving vertically towards the top of the window, it is applied a zoom factor of 100%. On the contrary, by holding down the select button at the center point of the window and moving vertically towards the bottom of the window, it is applied a zoom out factor of 100%. When the select button is released, the zooming stops. The command can also be activated from the Standard toolbar.

Previous Zoom

Activates the view immediately preceding the current one. The command can also be activated from the Standard toolbar.

Zoom All

Returns the full view of the project work within the drawing area.

> **Note**
>
> Zooming does not change the absolute size of the drawing, but the size of the view in the drawing area. The command can also be activated from the Standard toolbar.

In Drawing settings the user can set the display data in the grid, the tolerance of the cursor etc.

1.5 Computation

The falling motion of a boulder along a rocky slope depends on many factors that are not easy to express numerically.
The trajectories of the boulders depend on the geometry of the slope, on the shape of the falling boulder and on its initial velocity at the moment of detachment from the slope, and also on the entity of the energy dissipated due to the impacts during the fall. The falling boulders can slide, roll or

bounce downstream depending on their shape, flattened or rounded, and on the gradient of the slope.

The energy dissipated due to impacts is generally different and varies with the characteristics of the motion and depends on the mechanical characteristics of the boulder and on the materials present along the slope (rock, soil, vegetation) that oppose in a different manner to the motion of the boulders.
In reality, however, it is practically impossible to determine precisely the contour of a slope and detect the shape of the different boulders that may detach.

In addition, the geometry of the slope and the nature of the outcropping materials undergo changes over time, sometimes sensitive, as a result of the alteration of the rock, of the accumulation of debris in the less steep areas and of the development of the vegetation.
Finally, it is practically impossible to model the motion of boulders fall in cases in which these shatter due to impacts, nor is it possible to identify the areas of the slopes where shatter occurs.
For the analysis of the falling trajectories we need to refer to very simplified models: the geotechnical design of the protection interventions must be, therefore, developed on the basis of a large numerical experimentation, making it possible to explore the different aspects of the phenomenon and recognize the main factors that affect the motion of fall in the particular situation in question.
In more complex cases it might be necessary to calibrate the model on the basis of an analysis of trajectories detected by in situ cinematography following the collapse of the boulders.
There are two analytical models, Lumped-Mass and Colorado Rockfall Simulation Program (CRSP), used mainly to study the phenomenon of rock fall in an analytical way. In the Lumped-Mass model the falling boulder is considered as a simple point having a mass and velocity, and the impact on the ground is affected by the normal and tangential restitution coefficients. A more rigorous model is, however, the CRSP, as it takes into account the shape and size of the boulder.

Lumped Mass Method 23

By choosing this option, the computation of the trajectories is made with the Lumped Mass method (*hypothesis of point boulder*).

CRSP Method 27

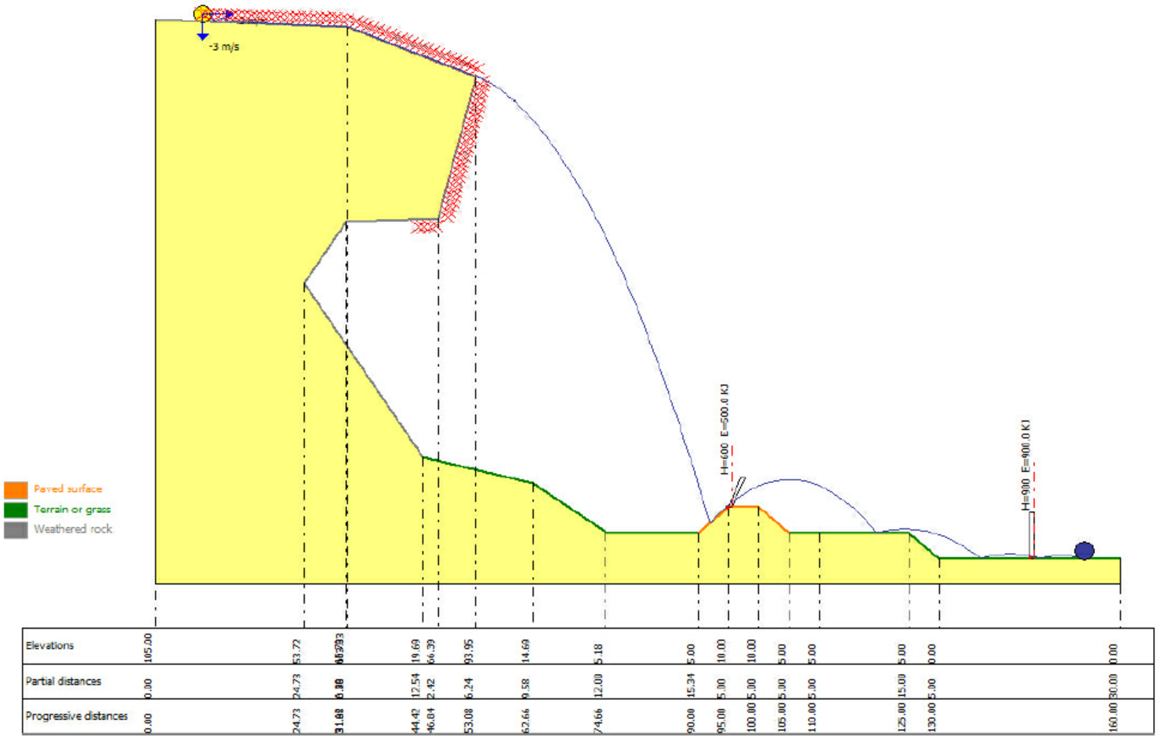
By choosing this option, the computation of the trajectories is made with the Colorado Rockfall Simulation Program method (*hypothesis of three-dimensional boulder*).

Calculate

The calculation is based on the method chosen by viewing the trajectories followed by the boulder on the basis of its dimensions and of the restitution coefficients. When the calculation is performed in the side panel of the work area is shown the information on individual trajectories: *order number, representation color, description* and *maximum abscissa reached.*

Option for the visualization of trajectories defined in the calculation. To display, proceed as follows:

- Choose "*Show single trajectories*".
- On the side panel, choose the trajectory to be displayed on the screen.
- Select a single trajectory clicking in the grid on the trajectory to display.
- Move the mouse over the work area: scrolling the mouse cursor along the trajectory on the status bar (the bar at the bottom of the worksheet) will be shown the values of the velocity of the boulder, the height of the trajectory and the energy of the boulder.
- For the chosen trajectory, in the grid below, a discretization of the trajectory is carried out at a constant pitch and, for each abscissa X, is returned to the flight time, the height of the trajectory at point X, the velocity and energy of the boulder. The data grid can be copied and pasted into Excel.
- Moreover, in correspondence of the single trajectory, with the data reported in the table, the program allows the generation of graphics of heights, velocity and energy. These charts are created directly on the section and can be printed with the command "Print Preview".



Info on single trajectories

By selecting this option, the user can get information on individual trajectories. To do so, proceed as follows:

- On the grid "Show single trajectories", select the path to be displayed.
- Scroll with the mouse over the points of the selected trajectory, it will open a label that will show step by step the values of impact velocity, the height of the parabola with respect to the profile of the slope, the fraction of flight time in that point and the value of the kinetic energy of the boulder in that point.

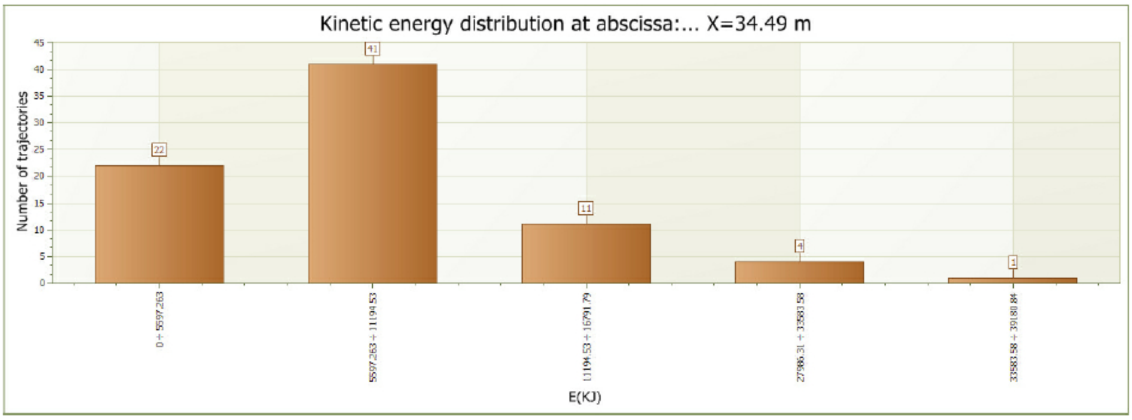
Report for % boulders not passing

Returns the values of % of boulders intercepted at each abscissa. Selecting this command is displayed a dialog box in which it is required the scanning step of the horizontal axis: each X shows the percentage of stopped boulders, and, by selecting the option "*Show Mesh % stopped boulders*" are shown the corresponding percentages along the path of the boulder.

Graphic parameters

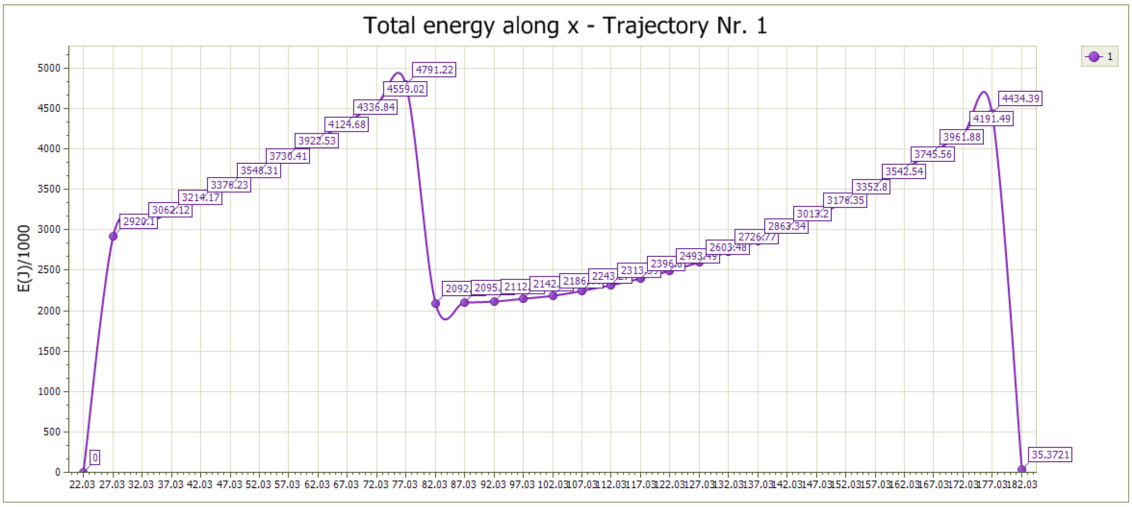
In this panel can be configured the settings for the proper display of the graphics given below. In particular, for the "*Energy histogram*" can be chosen the representation step of the energy by typing the value in the "*Display step*" field, or set the program to define it automatically. For "*Energy distribution*" can be chosen the step with which to vary the abscissa where is computed the energy of the boulder and the representation factor of the energy for a more or less scaled view of the peaks. For the "*Parabola graphic*", similarly, must be set the representation factor for a more or less pronounced view of the height peaks.

The command builds a histogram which shows the distribution of the trajectories' energy at a particular point defined by the user.
On the abscissa are represented energies at intervals, while on the ordinate the number of trajectories that have an energy value of in one of the intervals in which it was discretized the abscissa axis.
To choose the point at which to calculate the energy the user must move on the work area and with a on a specific point. A table will appear asking the user to confirm or change the abscissa of the chosen point. After the confirmation the energy histogram is regenerated with the values of the corresponding energies.
The generation of the histogram is available after performing the computation.
The histogram can be copied to the clipboard and pasted as a bitmap: go on the histogram and press the right mouse button. From the menu the user can also choose to do a print preview and optionally print the graphic.

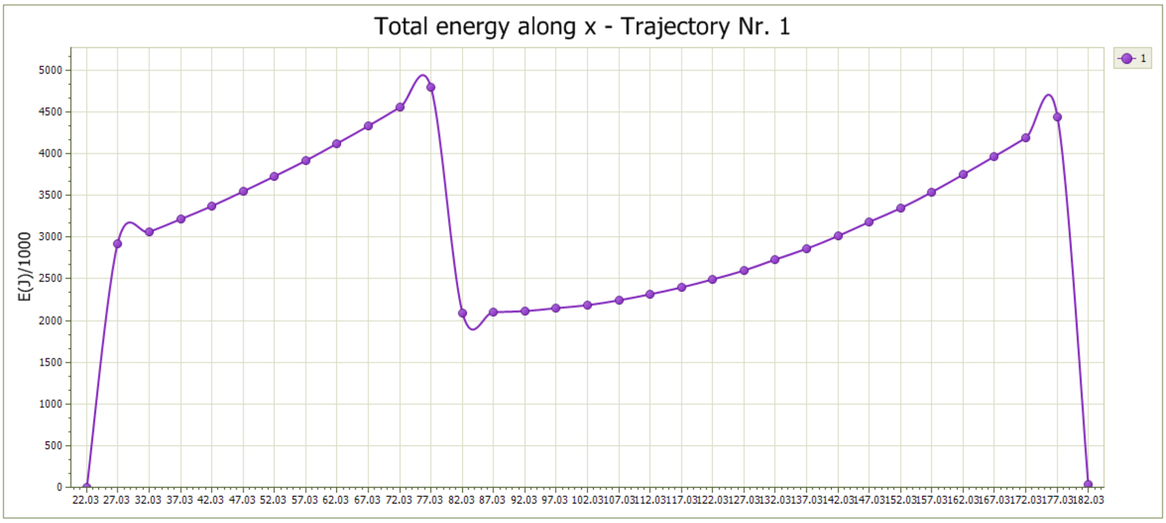


Represents, for each trajectory, the trend of the boulder's energy along the fall path. On the abscissa is represented the X (progressive distance along the profile), while on the ordinate is represented the energy of the boulder in the considered point. After performing the computation, a right

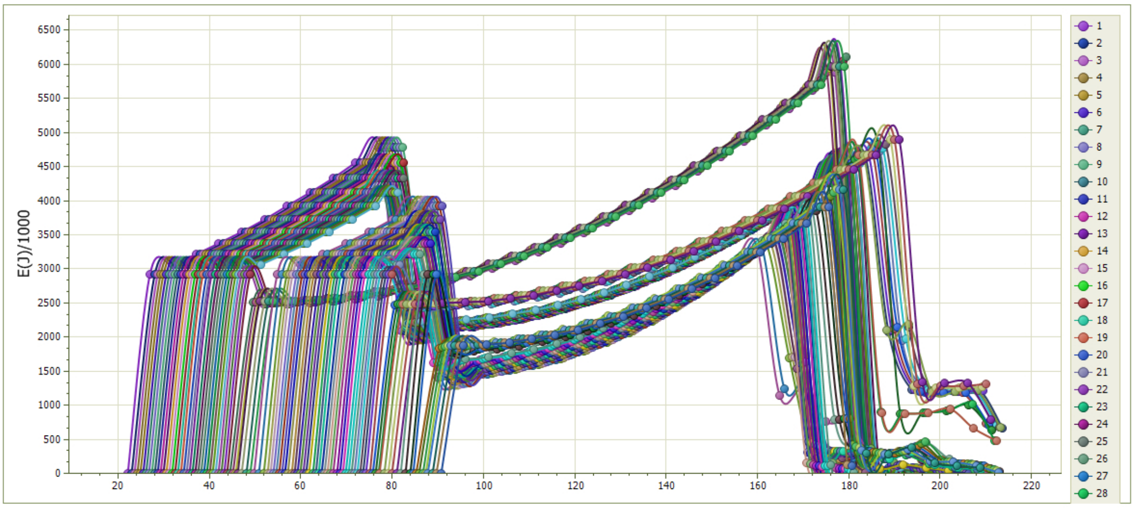
click brings up a selection window from which the user can choose the graphic to be displayed on the screen. The user is given the opportunity to make a choice on viewing single trajectory or view all the energy graphics associated to each trajectory. The representation of the set of graphics is done in sequence from left to right; for full view just move anywhere on the graphic and with the left mouse button scroll from right to left.
On the axes of the Cartesian reference system is present the scrollbar to move from left to right and from bottom to top on the Cartesian plane. This functionality is activated when the scale of graphical representation does not allow to obtain a complete representation of the graphic on the work area. The "*Envelope*" command is used to represent the set of all graphics of the energy associated with individual trajectories.
The user has the possibility to choose whether to display the labels with the values on the graphic. The option is activated with a right click , "*Labels*."
The graphics can be copied into memory to be subsequently pasted into Word or other applications, the user can also view the print preview of the work area. All operations can be performed by selecting the specific command after a right click.



with labels

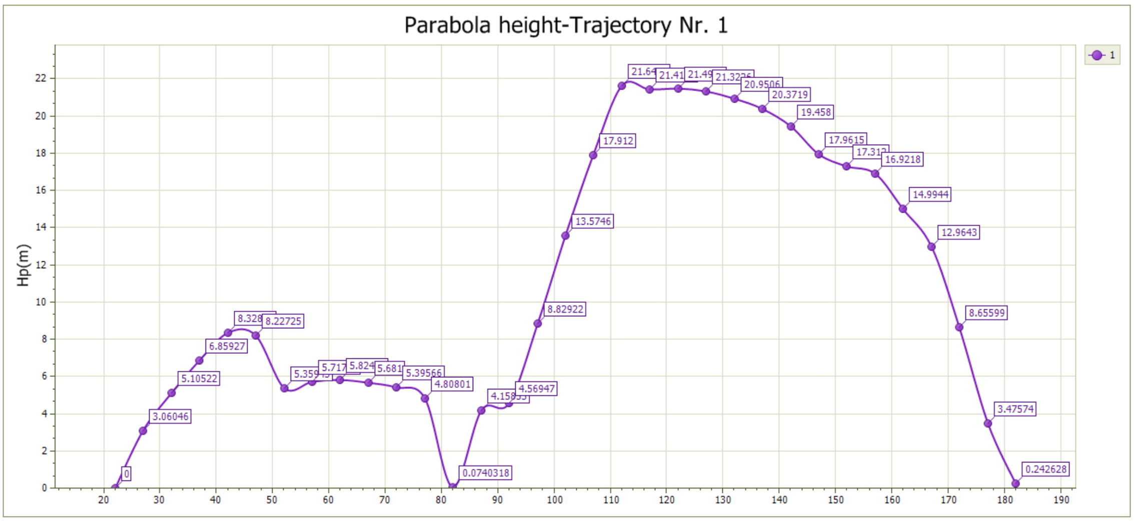


without labels

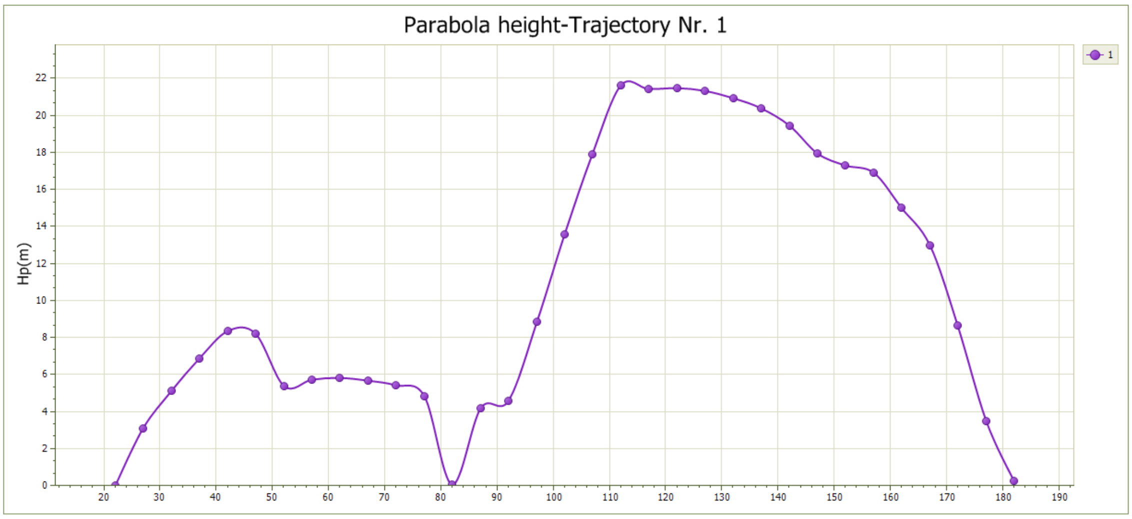


envelope

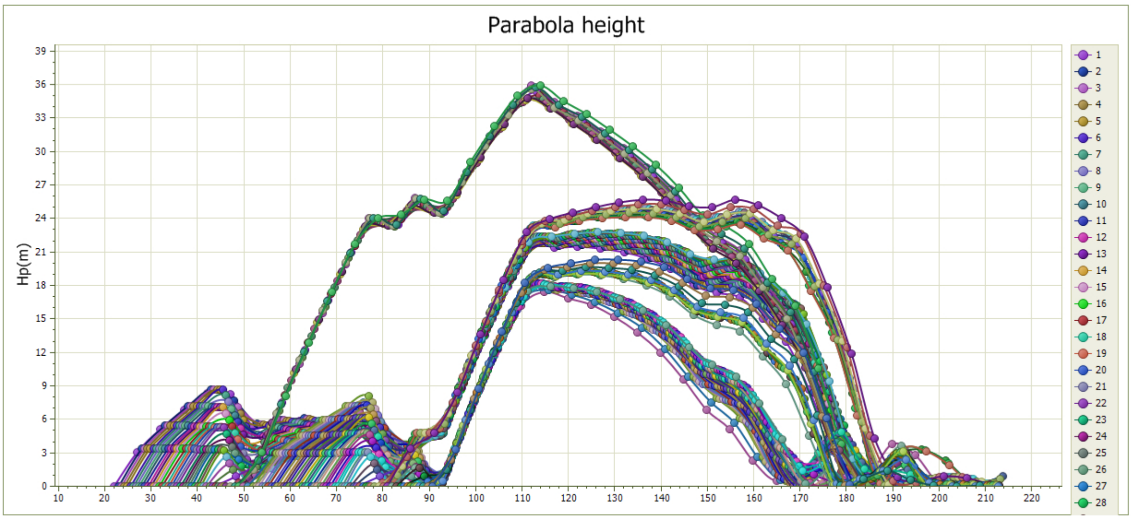
Trajectories graphic or parabolas' heights graphic, is the trend of the boulder's height along the fall path. On the abscissa is represented the X (progressive distance along the profile), while on the ordinate is represented the height of the boulder in the specific point. The graphic can be displayed using the same basis set out in the section "*Energy distribution graphic*".



with labels



without labels



envelope

Backfill

The template allows the user to create protection barriers (backfill). To insert them on the profile just confirm the assigned dimensions with "*Ok*", go on the work area with and choose the specific point of insertion with a simple click.

1.5.1 Calculation of Initial Velocity using the Impulse Theorem

The impulse theorem states that the impulse exerted on an object is equal to the change in the object's momentum. In formula, we can write it as:

$$I = \Delta p$$

Where:

- I is the impulse.
- Δp is the change in momentum.

Momentum p is defined as the product of mass m and velocity v:

$$p = m * v$$

If we know the force Fapplied to the mass and the time t during which this force is applied, the impulse I can be calculated as:

$$I = F * t$$

To find the initial velocity v0, we can express the change in momentum as:

$$\Delta p = m * v - m * v_0$$

Where:

- v is the final velocity.
- v_0 is the initial velocity.

Using the impulse theorem:

$$F * t = m * v - m * v_0$$

From which we can isolate the initial velocity v_0:

$$v_0 = v - (F * t) / m$$

Example Calculation:

Suppose we have a mass with the following characteristics:

- Mass m = 10 kg
- A constant force F = 50 N is applied for t = 4 s
- Final velocity v = 30 m/s

Let's calculate the initial velocity v_0:

1. Calculate the impulse:

$$I = F * t = 50 N * 4 s = 200 Ns$$

2. Using the formula to find v_0:

$$v_0 = v - (I / m)$$
$$v_0 = 30 m/s - (200 Ns / 10 kg)$$
$$v_0 = 30 m/s - 20 m/s$$
$$v_0 = 10 m/s$$

Therefore, the initial velocity of the mass was 10 m/s.

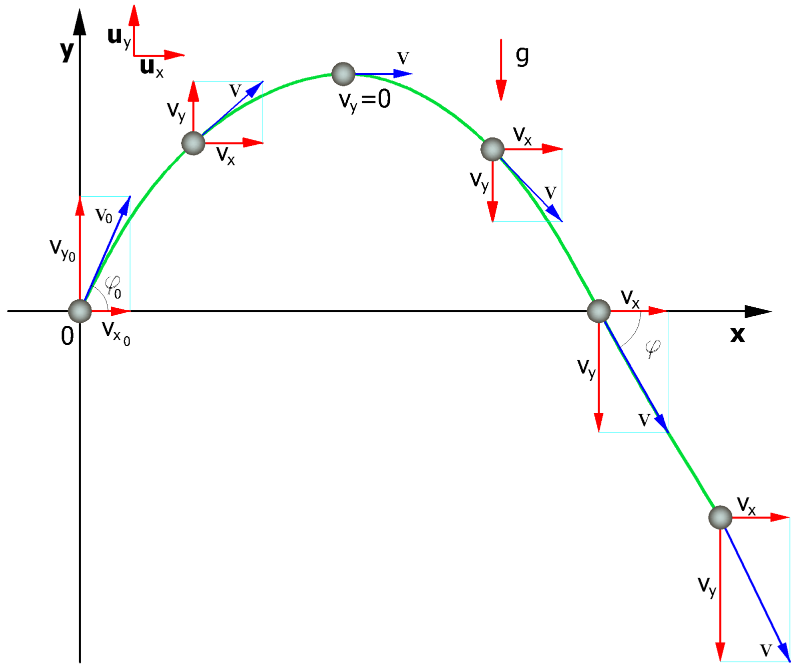
1.5.2 Lumped Mass

Lumped Mass model

The assumptions of the Lumped Mass model are:

1. plan outline, the slope profile similar to a broken line consisting of straight line segments
2. point boulder and neglectable air resistance

In this case the trajectory of the boulder can be determined using the equations of



The motion is characterized by a constant acceleration a=g=-g**u**$_y$ and the initial conditions are v=v0 at time t=0, moment of launch.
From the definition of acceleration in plane motion we obtain the following relation:

$$\vec{v}(t) = \vec{v}_0 + \int_0^t \vec{a}(t) \cdot dt = \vec{v}_0 - gt \cdot \vec{u}_y$$

as

$$\vec{v}(t) = \vec{v}_0 \cos\theta \cdot \vec{u}_x + \vec{v}_0 \sin\theta \cdot \vec{u}_y - gt \cdot \vec{u}_y$$

the velocities of the motion projected on the axes are:

$$v_x(t) = v_0 \cos\theta = \text{cost}$$
$$v_y(t) = v_0 \sin\theta - gt$$

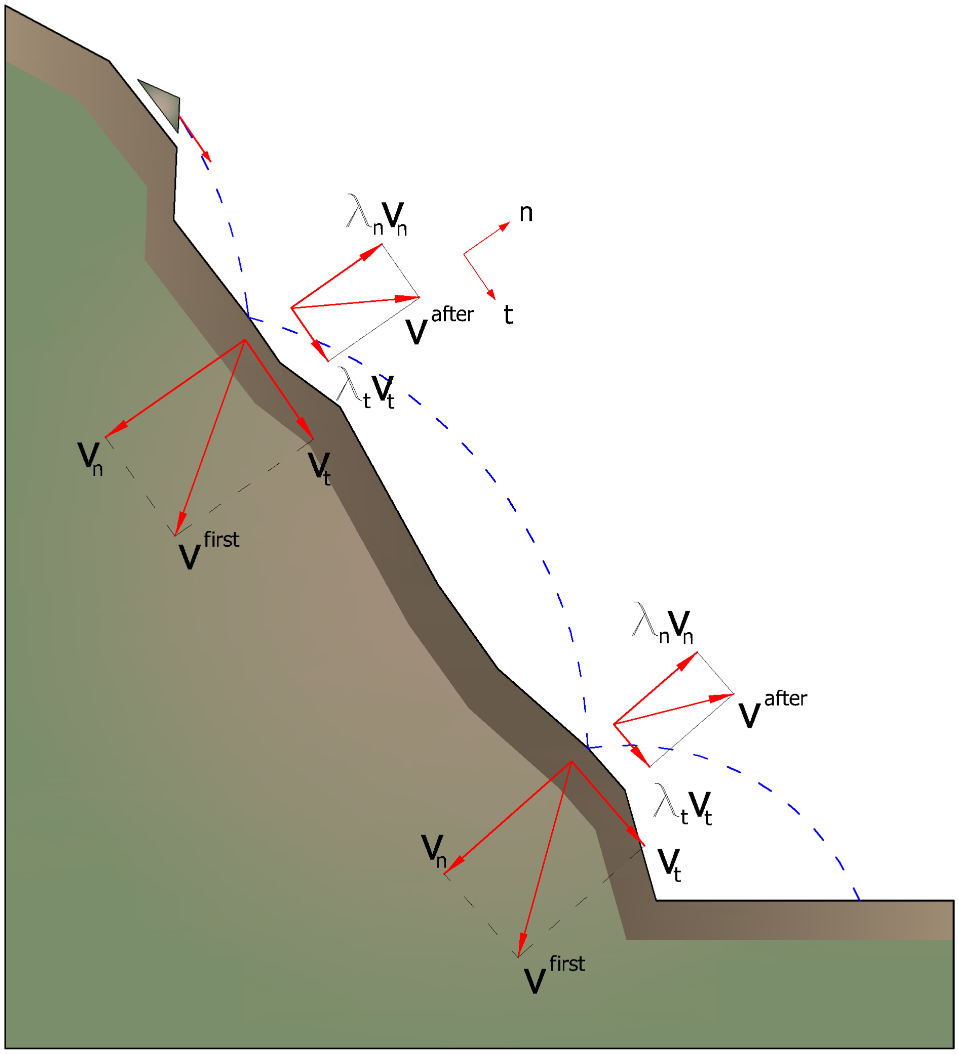
Referring to the same system of orthogonal Cartesian axes, the timing laws of the projected motions are:

$$x = v_x \cdot t + x_0$$
$$y = -\frac{1}{2} \cdot g \cdot t^2 + v_y \cdot t + y_0 \qquad (1)$$

where:

v_x horizontal component of the velocity of the boulder
v_y vertical component of the velocity of the boulder
t time
g acceleration of gravity
x_0 abscissa of the point where the boulder is detached from the slope or impacts in the falling motion
y_0 ordinate of the point where the boulder is detached from the slope or impacts in the falling motion

Along the x-axis the motion is uniform while along the y axis the motion is uniformly accelerated.



In this way the trajectory of the boulder motion is composed of a series of parabolas drawn between the point at which the detach takes place and the point at which the boulder collides on the slope for the first time, in the initial phase of motion, and between two successive impact points on the slope, or at the foot of the slope, later, to the stop point.
The coordinates of the impact points and velocity components are determined by solving the system between the equation (1) and the equation of the straight line representing the profile of the slope.
In practice we proceed from the point where the detachment of the boulder occurs and we resolve this system of equations considering in turn the different equations of the straight lines that contain the successive segments of the broken line up to finding the coordinates of a point, impact point, that belongs to the parabola that represents the trajectory and falls within of one of the segments of the broken line and is therefore also a point of the slope.

This point is the first impact point of the boulder on the slope. The procedure is repeated from that point to determine the next arc of the trajectory and a new impact point.
The loss of kinetic energy due to friction and impacts can be modeled by reducing the velocity of the falling boulder whenever this impacts on the slope.
In particular, indicating with v_n and v_t the components (normal and tangential) of the velocity before impact, after the impact v'_n, v'_t can be calculated using the relationship:

$$v'_n = v_n \cdot R_n$$
$$v'_t = v_t \cdot R_t$$

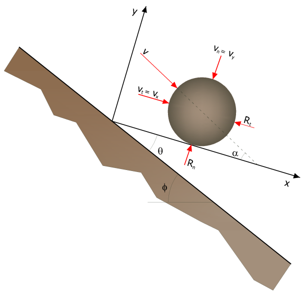
R_n and R_t are the restitution coefficients, variable in the range 0-1.

1.5.3 CRSP method

CRSP method

The **CRSP** model (Colorado Rockfall Simulation Program) has been developed by **Pfeiffer** and **Bowen** (1989) with the purpose of modeling the falling motion of boulders having the shape of spheres, cylinders or discs, with circular cross section in the vertical plane of the movement.
To describe the movement of the boulders the CRSP model applies the parabolic equation of motion of a body in free fall and the principle of conservation of the total energy.
The phenomenon of the impact is modeled using as additional parameters, compared to the Lumped Mass method, the roughness of the slope and the size of boulders.
In particular, the CRSP model assumes that the angle formed between the direction of the boulder and the profile of the slope varies according to a statistic that must be defined for each analyzed case. The model considers statistically also the results that mainly consist in the velocities and bounce heights, as compared to the surface of the slope, during the fall path. So the model considers the combinations of movements of free fall, of bounce, rolling and slipping, which can vary depending on the size of the boulders and the roughness of the slope.
The reliability of the model was verified by comparisons between numerical results and the results obtained from in situ tests.
The description of the motion of free fall starts from a point in which the initial velocity is known and is decomposed into its horizontal and vertical components. The boulder is subjected to the movement of free fall until it collides with the surface of the slope.

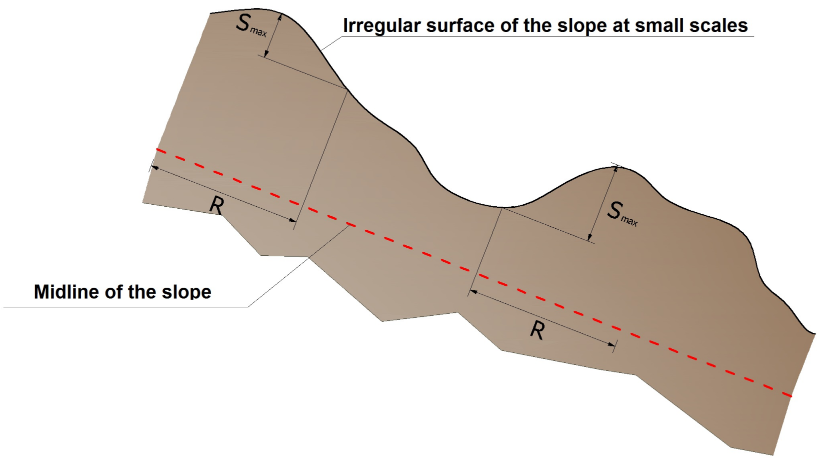
From the intersection are obtained the coordinates of the impact point. The velocity vector of pre-impact V, forms an angle α with the slope.



For each impact, the angle of the slope ϕ is varied randomly in a range of values between 0 and θ_{max}. The value of θ_{max} depends on the roughness of the slope and on the size of the boulder and is determined by in situ measurements. Being R the radius of the boulder under consideration we have:

$$\tan \theta_{\max} = \frac{S_{\max}}{R}$$

The angle θ_{max} is defined as the maximum variation of the average inclination compared to the radius R of the boulder.



The velocity that is obtained as a result of the impact is determined by the conservation equation of the total energy expressed as follows:

where:

- **R** Radius of the boulder
- **M** Mass of the boulder
- **J** Moment of inertia of the boulder
- ω_1 Angular velocity before impact
- ω_2 Angular velocity after impact
- V_{t1} Tangential velocity before impact
- V_{t2} Tangential velocity after impact

The function of friction f(F) is defined:

$$f(F) = SF + \frac{(1 - R_t)}{\left[\left(\frac{V_{t1} - \omega_1 \cdot R}{20}\right)^2 + 1.2\right]}$$

While the scale function SF is defined:

$$SF = \frac{R_t}{\left[\left(\frac{V_{n1}}{250 \cdot R_n}\right)^2 + 1\right]}$$

The terms f(F) and SF are obtainable through empirical expressions that are used to assess the kinetic energy dissipated in collisions between the boulder and the slope because of friction and impact.
The friction is primarily concerned with the dissipation of the energy produced by the tangential velocity, while the impact the energy produced by the velocity normal to the slope.

The tangential and angular post-collision velocities are related between them by the following equation:

which assumes that the boulders leave the contact with the slope rotating, regardless of the previous angular velocity.
The normal post-collision velocity is obtained by the following empirical expression:

$$V_{n2} = V_{n1} \cdot \frac{R_n}{\left[1 + \left(\frac{V_{n1}}{9}\right)^2\right]}$$

that will to take account of the fact, also verified experimentally, that the ratio between the normal post-impact and pre-impact velocities decreases with the increase of the normal pre-impact velocity itself.

Normal restitution coefficients

Tangential restitution coefficients

Radius of the boulder

2 Utility

2.1 Conversion Tables

Converting slope inclination into degrees and vice versa

Inclination (%)	Angle (°)	Inclination (%)	Angle (°)
1	0.5729	26	14.5742
2	1.1458	27	15.1096
3	1.7184	28	15.6422
4	2.2906	29	16.1722
5	2.8624	30	16.6992
6	3.4336	31	17.2234
7	4.0042	32	17.7447
8	4.5739	33	18.2629
9	5.1428	34	18.7780
10	5.7106	35	19.2900
11	6.2773	36	19.7989
12	6.8428	37	20.3045
13	7.4069	38	20.8068
14	7.9696	39	21.3058
15	8.5308	40	21.8014

16	9.0903		41	22.2936
17	9.6480		42	22.7824
18	10.2040		43	23.2677
19	10.7580		44	23.7495
20	11.3099		45	24.2277
21	11.8598		46	24.7024
22	12.4074		47	25.1735
23	12.9528		48	25.6410
24	13.4957		49	26.1049
25	14.0362		50	26.5651

Forces conversion

From	To	Operation	Factor
N	kg	Divide by	9.8
kN	kg	Multiply by	102
kN	Tone	Divide by	9.8
kg	N	Multiply by	9.8
kg	kN	Divide by	102
Tone	kN	Multiply by	9.8

1 Newton (N) = 1/9.81 Kg = 0.102 Kg 1 kN = 1000 N

Pressures conversion

From	To	Operation	Factor
Tons/m^2	kg/cm^2	Divide by	10
kg/m^2	kg/cm^2	Divide by	10000
Pa	kg/cm^2	Divide by	98000
kPa	kg/cm^2	Divide by	98
Mpa	kg/cm^2	Multiply by	10.2
kPa	kg/m^2	Multiply by	102
Mpa	kg/m^2	Multiply by	102000

1 Pascal (Pa) = 1 Newton/mq 1 kPa = 1000 Pa

2.2 Database of soil physical characteristics

Approximate values of the tangential restitution coefficient (Rt) for the various morphological categories

MORPHOLOGY	R_t
Bedrock	0.87
Outcrops of rock debris	0.85
Coarse debris not vegetated	0.85
Average debris not vegetated	0.83
Vegetated debris with shrubs	0.70
Vegetated debris in forest	0.60
Bare soil or lawn	0.55
Paved surfaces	0.90

Approximate values of the normal restitution coefficient (Rn) for the various morphological categories

MORPHOLOGY	R_n
Bedrock	0.40
Outcrops of rock debris	0.38
Coarse debris non-vegetated	0.35
Average debris not vegetated	0.31
Vegetated debris with shrubs	0.30
Vegetated debris in forest	0.28
Bare soil or lawn	0.25
Paved surfaces	0.40

Approximate values of the unit weight in Kg/m3

Soil	Minimum value	Maximum value
Dry gravel	1800	2000
Wet gravel	1900	2100
Compact dry sand	1700	2000
Compact wet sand	1900	2100
Loose dry sand	1500	1800
Loose wet sand	1600	1900
Sandy clay	1800	2200
Hard clay	2000	2100
Semisolid clay	1900	1950
Soft clay	1800	1850
Peat	1000	1100

Approximate values of the friction angle, in degrees, for soils

Soil	Minimum value	Maximum value
Compact gravel	35	35
Loose gravel	34	35
Compact sand	35	45
Loose sand	25	35
Sandy marl	22	29
Fat marl	16	22
Fat clay	0	30
Sandy clay	16	28
Silt	20	27

Approximate values of cohesion in Kg/cm2

Soil	Value
Sandy clay	0.20
Soft clay	0.10
Plastic clay	0.25
Semisolid clay	0.50
Solid clay	1
Tenacious clay	2÷10
Compact silt	0.10

Approximate values of the elastic module, in Kg/cm2

Soil	Maximum value of E	Minimum value of E
Very soft clay	153	20.4
Soft clay	255	51
Medium clay	510	153
Hard clay	1020	510
Sandy clay	2550	255
Loess	612	153
Silty sand	204	51
Loose sand	255	102
Compact sand	816	510
Clayey schist	51000	1530
Silt	204	20.4
Loose sand and gravel	1530	510
Compact sand and gravel	2040	1020

Approximate values of the Poisson ratio for soils

Soil	Maximum value of n	Minimum value of n
Saturated clay	0.5	0.4
Not saturated clay	0.3	0.1
Sandy clay	0.3	0.2
Silt	0.35	0.3
Sand	1.0	-0.1
Gravelly sand commonly used	0.4	0.3
Loess	0.3	0.1
Ice	0.36	
Concrete	0.15	

Approximate values of specific weight for some rocks in Kg/m3

Rock	Minimum value	Maximum value
Pumice	500	1100
Volcanic tuff	1100	1750
Tufaceous limestone	1120	2000
Coarse sand dry	1400	1500
Fine dry sand	1400	1600
Wet fine sand	1900	2000
Sandstone	1800	2700
Dry clay	2000	2250
Soft limestone	2000	2400
Travertine	2200	2500
Dolomite	2300	2850
Compact limestone	2400	2700
Trachyte	2400	2800
Porphyry	2450	2700
Gneiss	2500	2700
Serpentine	2500	2750
Granite	2550	2900
Marble	2700	2750
Syenite	2700	3000
Diorite	2750	3000
Basalt	2750	3100

2.3 Shortcut commands

The bar shown in figure below can be used for a variety of functionalities:

1) With the shortcut letters of the menu followed by Enter you have quick access to commands.

Ex: **N + Enter** to create a new file.

2) You can ask a question followed by ? + Enter. In this case an advanced research will be made in the Help manual.

Ex.: **Seism+?+Enter** for information on seismic analysis.

3) Opening a program in a quick way.

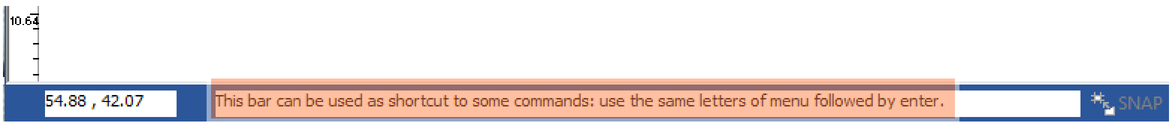
Ex.: **Slope+Enter** to open GeoStru Slope software.

4) Quick access to GeoStru contacts.

Ex.: **Contact+?+Enter** to access the contact list.

5) Quick access to web features:

Ex.: www.geostru.com**+Enter** or geostru@geostru.com**+Enter**



Shortcut commands bar

3 Geoapp

Geoapp: the largest web suite for online calculations

The applications present in Geostru Geoapp were created to support the worker for the solution of multiple professional cases.
Geoapp includes over 40 applications for: Engineering, Geology, Geophysics, Hydrology and Hydraulics.

Most of the applications are **free**, others require a monthly or annual **subscription**.

Having a subscription means:

- access to the apps from everywhere and every device;
- saving files in cloud and locally;
- reopening files for further elaborations;
- generating prints and graphics;
- notifications about new apps and their inclusion in your subscription;
- access to the newest versions and features;
- support service throught Tickets.

3.1 Geoapp Section

General and Engineering, Geotechnics and Geology

Among the applications present, a wide range can be used for GeoRock. For this purpose, the following applications are recommended:

- ✓ Anchored mesh systems
- ✓ Nailing passive bars
- ✓ Rigid and elastic rockfall barriers
- ✓ Tiranti
- ✓ Analysis stability of flat surfaces
- ✓ Slips along a plane

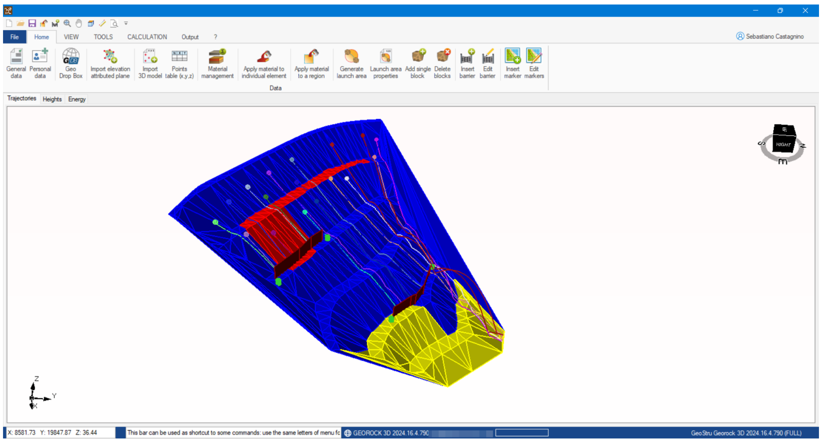
4 Software Geomechanical rocks

GEOSTRU software – among the most successful software worldwide – highly advanced software products and services in the following fields: civil engineering, geotechnical engineering and geology, **geomechanics software**, geophysics, in situ soil testing, hydrology and hydraulics, topography.
The software is characterized by an intuitive interface and face every single geological problem in 2D-3D environment.
The main suite includes a number of geology programs, fully integrated with each other, characterized by a very competitive cost and a quality guaranteed by over 30,000 installations. The software is widespread in more than 135 countries around the world.
The software GEOSTRU is very easy to use, each software solves a specific problem, reducing the input data to the strictly necessary. Furthermore, being integrated with each other, you have the possibility to export data from/and for each software in the suite.
All products are fully compatible with the Eurocodes, in particular EC7 for geotechnical design, EC8 for the seismic design, EC2/3 for structural design and checks and also allow user custom parameters.

The complete suite for Geomechanics of rocks can be viewed here: [Geostru geomechanics software - Software for rocks mechanics]

- Geomechanical survey;
- Rock classification;
- Stability analysis;
- 2D and 3D rockfall analysis;
- Rock consolidation

5 Rock falls 3D – GeoRock 3D



GeoRock 3D is a program for the three-dimensional analysis of rock falls and for designing and optimizing protective works utilizing a sophisticated algorithm for spatial analysis.

SLOPE MODELLING

The slope in question is generated from an XYZ mesh that may be imported from various formats or suitable external software.
The triangulation technique is essential, and it is recommended that Incremental Delaunay or anisotropic triangulation are used.
In this respect, the Geostru software "TriSpace" is eminently suitable.
A tridimensional model can be imported directly from chart work/maps using Geostru Autocad Application (G.A.A.)

TERRAIN PROPERTIES

The slope is discretized in homogeneous zones having similar mechanical characteristics, namely standard and tangential restitution coefficients.

BLOCK CHARACTERISTICS

From a geometrical point of view, the block is characterized by a spherical form rotating around its centre of gravity, while its mechanical characteristics are hardness and mass.

LAUNCH SITES

Launch sites can be indicated directly on the 3D model specifying, for each launch, the launch velocity.

CALCULATION

This provides three-dimensional trajectories, speed and energy.

PROTECTIVE WORKS

Protective works can be inserted directly on the 3D model and their position optimized concerning the displayed trajectories.

BARRIER ARCHIVE

Facilities are provided for an archive of standard barriers that may be utilized directly on the 3D model.

PROTECTIVE WORKS SIZING

Geostru Software provides a BARRIER DESIGN (B.D.) tool for designing and verifying rigid or elastic barriers.

INTERFACES

This software interfaces with Geostru software TriSpace and Georock 2D.

More information about Rock falls 3D - Georock 3D:
Rock falls 3D - GeoRock 3D - GeoStru EU

6 GeoStru Software

The GeoStru Software company develops technical and professional software for geotechnical engineering, civil engineering, geology, geomechanics, hydrology, soil testing, geophysics.

Thanks to GeoStru Software you can now use the most effective tools for your own profession. The GeoStru software represents a complete, reliable (the computation algorithms are the most technologically advanced in the research field worldwide), regularly updated, easy to use tool with an intuitive user interface.
Attention to customer service and the development of software using modern technologies allowed us to become one of the strongest companies in the field on international markets. The software – currently translated into eight languages – is compatible with international computation rules / normatives and it is one of the most used in over 50 countries worldwide.
GeStru is always present at the main exhibitions in the field, both in Italy and abroad SAIE Bologna, MADEEXPO Milano, GeoFluid Piacenza, ExpoEdilizia Roma, Restructura Torino, SEEBE Belgrad, Construct EXPO Bucuresti, EcoBuild Londra, Construtec Madrid, The Big 5 Dubai etc.
Today working with GeoStru is more than just buying software – it means having beside you a team of professionals willing to share their knowledge and experience for excellent results.

There are many areas where the company has specialized in over the years.
The family of GeoStru products is, in fact, divided into several categories:

- Structures
- Geotechnics and geology
- Geomechanics
- In situ soil tests
- Hydrology and Hydraulics
- Topography
- Energy
- Geophysics
- Office

For further information about our products please visit our website http://www.geostru.com

Among the many services offered by GeoStru Software you can use the free service GeoStru Online that includes software applications on the web that will help you solve many different problems.

6.1 Autoupdate

The software comes with an integrated auto-update system.

A few seconds after opening the software, by moving the mouse pointer on the indication of version (shown in the bottom right side of the main window: Geostru 201x._._._), the user can check whether or not it is available an update of the software.
If a message will warn the user about the availability of an updated version, the user can automatically update the software by clicking on the icon of the message.
In the event that there are no updates available, the message shown will be *''No updates available.''*

6.2 Copyright

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6.3 Customer technical support service

For any queries regarding a GeoStru product:

- Consult the documentation and other printed material
- Consult the Help OnLine section
- Consult the technical documentation used for software development (Web Site)
- Consult the FAQ area (Web Site)
- Consult the GeoStru support services (Web Site)

It is active the new ticket support service developed by GeoStru Software in order to respond to our users support requests.
This service, reserved to registered users and owners of valid licenses, allows you to get answers to your requests regarding different aspects of your programs directly from our specialists (Web Site).

Web Site: www.geostru.com

6.4 Contact

Web: www.geostru.com

See the contact page on the website for more information about our contacts and offices' addresses in Italy and abroad.