AN EXPERIMENTAL STUDY RELATED TO ROCK FALL MOVEMENT MECHANISM

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Abstract:In this experimental study, natural rock pieces as well as concrete balls and cubes having imbedded accelerometers in them were made to fall and roll over a 45m high natural slope composed of exposed rocks and vertical planes in an attempt to elucidate further the mechanism of rock fall movement overthe slopes and the energy associated with the movement. As a result the following points were mainly clarified: 1) flight and collision are the main forms of the rock fall movement; 2) collision causes ground destruction, thereby resulting in loss of energy, so the bouncing velocity becomes the critical velocity; 3) bigger the size of the falling rock piece, higher the falling velocity; 4) when bounced from a gentler portion of the slope, the flight time becomes longer with greater bouncing height and higher collidingvelocity; 5) the reduction in velocity is high when the angle of collision is small; 6) equivalent friction coefficient changes with the falling movement; and 7) the geometric configuration of the slope governs the amount of bouncing height.

Key Words : *rock fall, field experiment, falling velocity, rolling velocity, bounce height, kinetic energy*

1. Indroduction

The movement of the rockfall is influenced by the inclination of slope, a local rughness, the geographical feature, vegetation, shape and size of rockfall, it is difficult to be predicted only by the theoretical analysis.

After the site falling rock experiment is conducted in the Iwanai-cho thunder cape in 1961, it is executed in the place that the falling rock experiment to clarify the movement mechanism shows in Figure 1 in Japan[1)-14)]. These results of the research are arranged as "Rockfall measures handbook"[15)] and "Reference concerning the Rockfall measures handbook"[19)] and, it is widely used by the business of the design. However it is a limit in an applicable condition because the forecast method of the rockfall movement shown in Rockfall measures handbook was based on the empirical assumptions from the rockfall experiment in the past.

Recently, The efficient excelling in the energy absorption performance and the economy, various, type defense hedge competes, it is developed, and a construction real product increases rapidly. But applying "Rockfall measures handbook" to a large target rockfall for the efficient type defense hedge or the rockfall from the long slope has the problem.

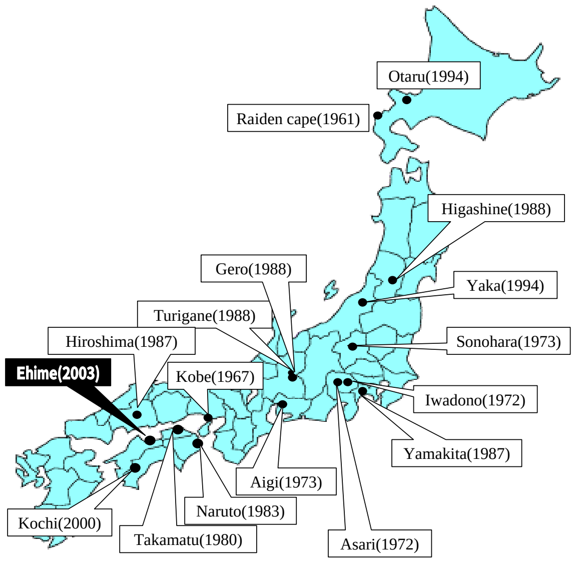


Figure-1 The main site falling rock experiment in the past(Retouch it in Osamu's Matsuo figure.)

Therefore, the case where the fall cources and the velocity of the rockfall are predicted by the numerical simulation has increased in the design of the efficient type defense hedge. The result of the numerical simulation is ruled by how concerning modeling the slope and the rockfall and slope property to give the parameter. Therefore, it is important to verify the validity of modeling and the parameter compared with the rockfall experiment result on a similar slope.

However, the experiment conducted aiming to obtain basic data of the numerical simulation is a little in the rockfall experiment in the past. Moreover, the measurement equipment has not developed, and it is difficult to obtain accurate

Photograph-1. Experiment slope

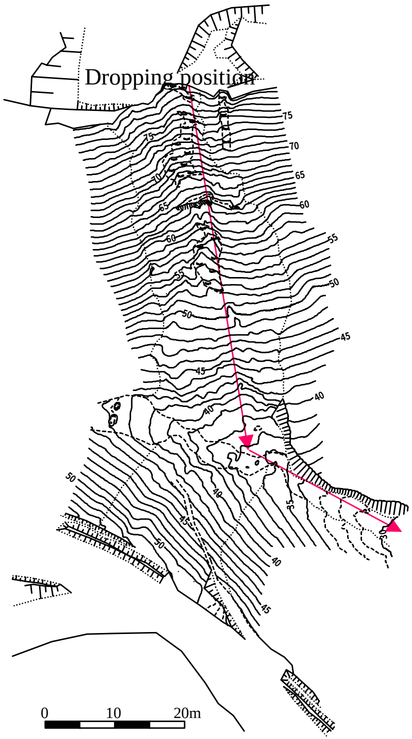


Figure-2. Plane surface of experiment slope

data.

The purpose of this research is a verification of the validity of the empirical assumptions that the movement mechanism of the falling rock is used in detail by the business of the examination design, and to obtain basic data in the numerical simulation of the falling rock. It is the one that the rockfall experiment was executed in the natural slope in the site Ehime Macadam industry Ltd. in the Ehime Prefecture Uma-gun Doi-cho.

2.Outline of rockfall experiment

(1) Experiment slope

The slope does the ravine geographical features shown in photograph-1 and Figure-2. Slope height is about 41m. The radical bedrock where sandstone and mudstone is piled up the alternation of stratas is exposed within the range of 25m in the upper part, and the talus cone piles up in the lower side.

The inclination angle on the bedrock slope is about 44 degrees. The degree of rebound with the Rock Schmidt hammer is 17.7～38.6. As a result, unconfined compressive strength is assumed to be 6～27MPa. The rock class division is CL～CH. The inclination angle on the talus cone slope is about 35 degrees. In the diameter of gravel that composes the talus cone, 2-5cm is 68%, 5-10cm is 24%, and 10-50cm is 8%. The pine and the oak etc. of the trunk of 10-20cm in the diameter have grown sparsely on the talus cone slope.

(2) Rockfall

The falling rock used to experiment is a globe and a cube made of concrete, and 11 kinds of rock block (0.12-2.06t in mass) shown in photograph -2. Design strength of the rockfall made of concrete is 50MPa. The acceleration sensor and the data logger of three dimensions are buried under its inside. Rock block is sandstone cut out in the stone quarry. The compressive strength is 200MPa, and the density is 2.6t/m3.

(3) Experiment method

The rockfall was carried to a fixed position in the upper part of the slope of the grip with the fork, and the fork was opened with ground touched and bottom was made to fall by the self-respect. However, because the cube block rolled in the self-respect and did not fall, it lightly pushed it out the fork ahead.

The movement of rockfall took a picture of 14 in total digital video cameras (30 scenes/second) on the right and left

Concrete ball
(D=0.54m, 200kg)
Concrete cube
(D=0.6m, 520kg)
rockblock(2,060kg)
rockblock(160kg)

Photograph-2. Falling rock used to experiment

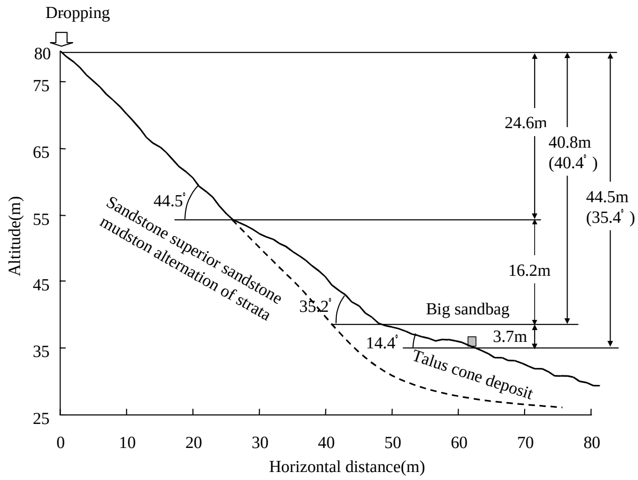


Figure-3. vertical of experiment slope

Table-1. Kind of experiment

Slope state	kind of rockfall	Mass of rackfall(kg)	Falling total
tree having	globe	200	5
	cube	520	5
	rockblock	120,160,550,790,990,990 1260,1320,1330,1360	10
tree none	globe	200	5
	cube	520	5
	rockblock	120,160,550,790,990,1260, 1320,1330,1360,2060	10

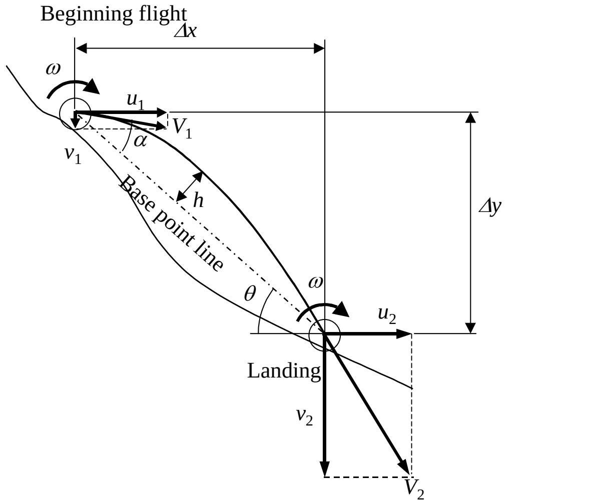


Figure-4. Explanation of sign the rockblock in the experiment.

and the slope of the slope upper part, the front, and the fall route by setting it up.

The accelerometer buried under the rockfall made of concrete enters the moment that seceded from the fork the switch, and records the acceleration element of three directions for 60 seconds or less at intervals of 1/2000 seconds. The switch is turned off when the rockfall stops, and the acceleration data is taken into the personal computer.

Before a slope tree was deforested and after it had deforested it was dropped respectively five times as for the globe, five times as for the cube, and ten times as for the rockblock in the experiment.It falls collecting after it drops it and repeatedly about the globe and the cube. (Table 1)

3.Method of calculating velocity and bounce height

The keep abreast of velocity, the angular velocity, and the bounce height of the rockfall were requested from the measurement data of the point where the rockfall had done the flight movement.

The distance between coordinates of the Beginning flight point and the landing point is $\varDelta x$, $\varDelta y$ and the flight time are $\varDelta t$ as shown in Figure 4. Then, first velocity $V_1(u_1,v_1)$ and landing velocity $V_2(u_2,v_2)$ can be calculated by expression (1). The coordinate value of the Beginning flight point and the landing point is requested from the video image analysis. The flight time of the falling rock made of Conret is stopped at inttervals between the top and the top of the impact acceleration wave form of time. It requests it from the number of scenes flying from the video image as 30 scenes/a second in flight time of rockblock.

The falling rock under the flight requested the made number of scenes from the angular velocity ω by the half rotation or one rotation reading it from the video image.

The bounce height h is calculated by expression (2). The line where the beginning flight point was connected with the

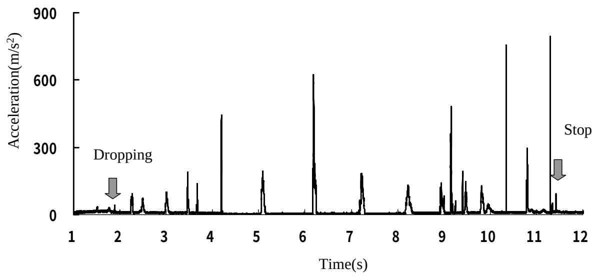


Figure-5. Example of acceleration wave form(After deforesting the tree, it is a globe block.)

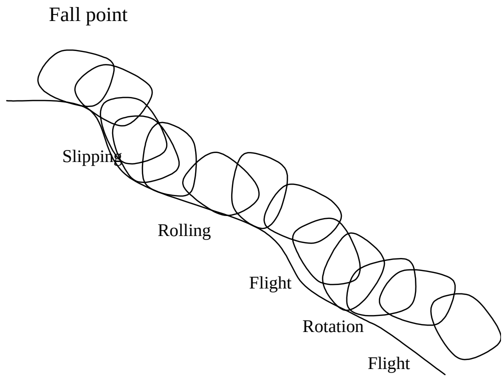


Figure-6. Pattern diagrams in movement form of rockblock

Photograph-3. Cubic block fall situation(After deforesting the tree.)

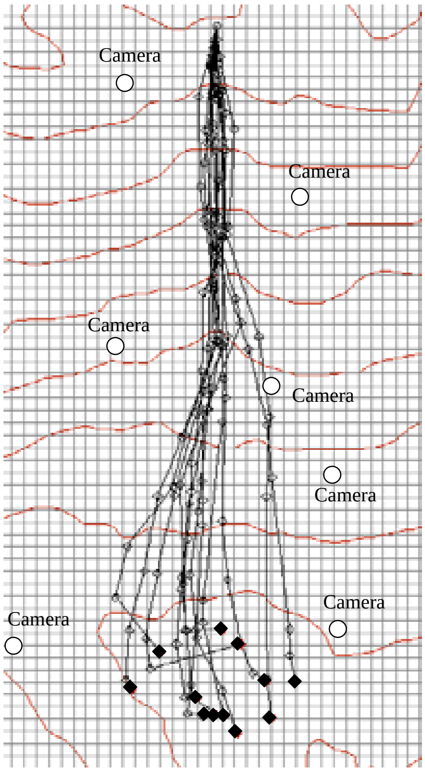


Figure-7 Plane surface fall route of rockblock

center of gravity of falling rock in the landing point by the straight line is assumed to be a base point line. And, the maximum value of the vertical direction distance to the flight tracks that the center of gravity of the falling rock draws from the base point line is assumed to be bounce height h.

$$\left.\begin{aligned}
&V_1=\sqrt{{u_1}^2+{v_1}^2} \quad , \quad V_2=\sqrt{{u_2}^2+{v_2}^2} \\
&u_1=u_2=\frac{\Delta x}{\Delta t} \\
&v_1=\frac{\Delta y}{\Delta t}-\frac{1}{2}g\Delta t \quad , \quad v_2=v_1+g\Delta t \\
&\alpha=\theta-\tan^{-1}\frac{v_1}{u_1}
\end{aligned}\right\} \qquad (1)$$

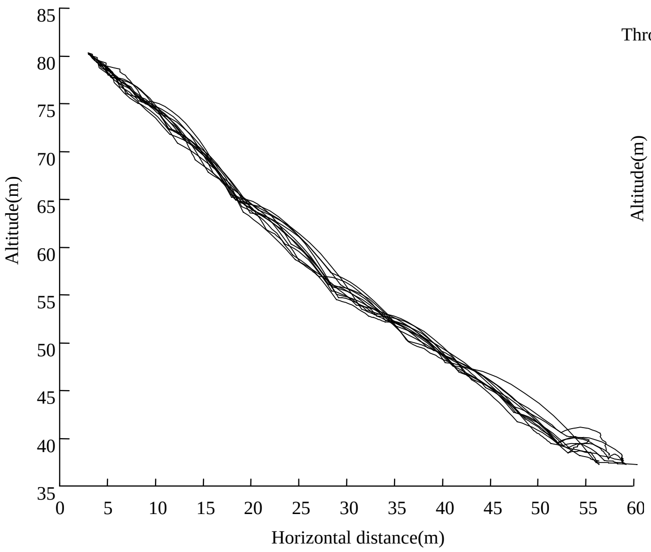


Figure-8. vertical through fall route of falling rock
(After deforesting the tree.)

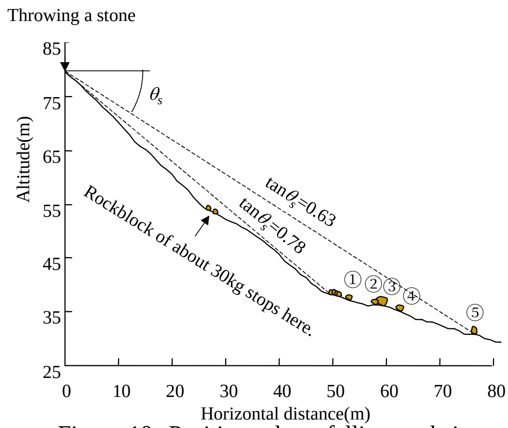


Figure-10. Position where falling rock in preliminary experiment is stopped(Before the tree of deforestation, rockblock)

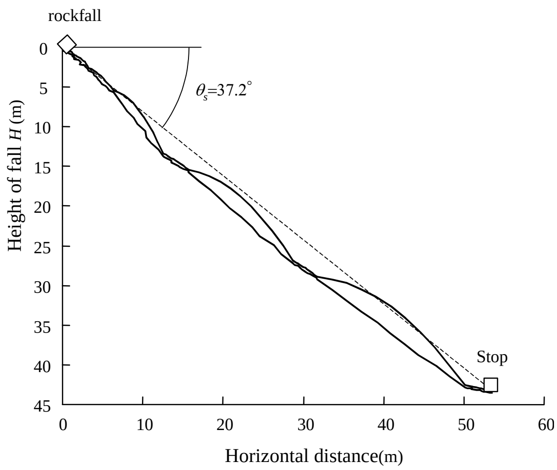


Figure-9. Cubic block vertical through fall route
(After deforesting the tree.)

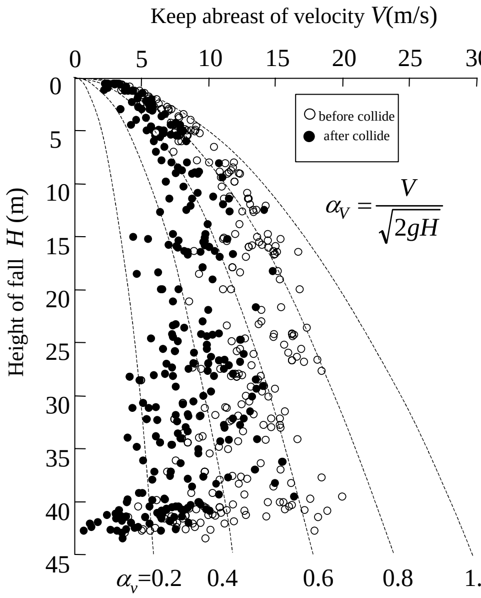


Figure-11. Relation between fall amount and keep abreast of velocity(all cases)

$$h = \frac{(V_1 \sin\alpha)^2}{2g\cos\theta} \tag{2}$$

4.Experiment result

(1) Movement mode of rockfall

Photograph-3 shows one example of the fall situation by the cube block after the tree is deforested. The position in which the image of the falling rock is reflected is a collision point. And, the flight movement between the image and the image is done.

Figure 5 is one wavy example to request from the accelerometer built into the globe block. Because the shock wave appears when the slope comes in contact, movement mode can be identified.It shifts immediately to the flight though the rockfall slightly causes slipping and rolling immediately after dropping. Afterwards, it falls to the bottom of the slope repeating the collision and the flight. Colliding with the talus cone at the bottom of the slope and stopping at once are a little. However, it slips by several cm after it rotates a little and it stops. Figure 6 shows a movement mode the imitation type.

(2) Fall course and stop position

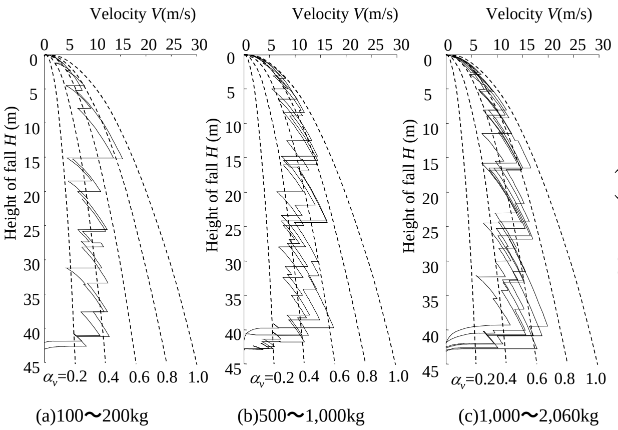


Figure-12. Mass and keep abreast of velocity of falling rock(After deforesting the tree. rockblock)

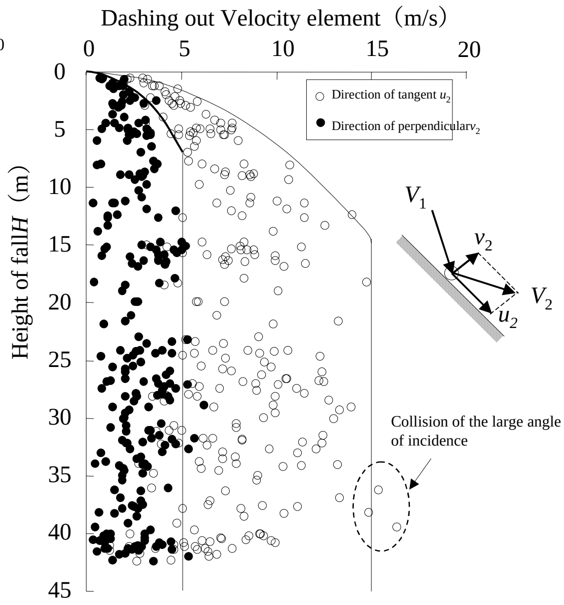


Figure-13. Beginning flight speed element after it collides (all cases)

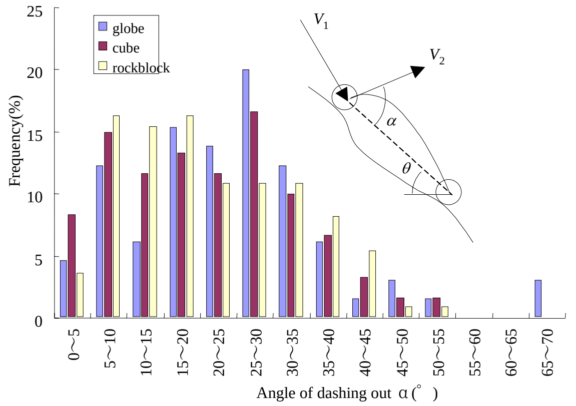


Figure-14. Beginning flight angle after it collides(all cases)

Table-2. Comparison of average landing velocity by presence of tree

	Before deforesting the tree	After deforesting the tree	Before/After
entire slope	8.11m/s	7.83m/s	1.04
Cliff weight slope	8.74m/s	8.12m/s	1.08

a) Plane surface fall route

Figure 7 shows the plane surface fall route of rock block. A remarkable difference did not appear before the tree was deforested and after it had deforested it. Therefore, it shows without distinguishing it. A white diamond in figure shows the collision point of the falling rock. Moreover, a black diamond shows the stop position. The rockblock falls in the upper part of the slope where bedrock was exposed along the ravine geographical features. The talus cone piles up from above sea level 55m below the fan form. Therefore, it extends right and left and it falls. The cube and rockblock extend obviously right and left and greatly compared with a concrete ball. The direction of the movement is decided by the state of the collision to the bedrock that has been exposed to above sea level about 55m.

b) Vertical through fall courses

Figure-8 shows the one that the jump courses along the fall route of all falling rocks were overlapped. Because the fall route is different in each experiment case, the ground line is not shown.

Figure-9 is cubic fall tracks where the biggest velocity appears. Flying range is large when beginning flight from the inclination part where the falling rock is gentle.

c) Stop position

11 rockbkock of about 30-1,200kg in mass was experimentally dropped before the experiment.

Small-scale rockblock of 30kg stopped in the vicinity of the boundary of the bedrock outcrop and the talus cone piling up part on the way the slope. The rockblock of 100kg or more stopped at the position of ①-⑤ shown in Figure 10. Inclination tan θ that connects the fall point with the stop position is 0.63-0.78.

To prevent it from a concrete ball's rolling along the valley and falling in the experiment, large-scale Sandbag was piled up at the position of ④. Therefore, all rockblock stopped from the position of ④ in this side.

(2) Velocity of rackfall

a) The Relation between the height of the fall and the keep abreast of velocity.

Figure 11 shows the relation between the height of the fall and the keep abreast of velocity. sign ○ velocity the velocity immediately before the falling rock collides with the slope and the beginning flight velocity after sign ● collides is shown. The upper bound at the velocity is near the free fall velocity up to 5m in fall height. However, 17-18m/s since 15m in fall height.

Figure-12(left) shows the appearance of the keep abreast of velocity change of the experiment case shown in Figure 9. The velocity is increased while flying. The beginning flight angle α is large, the slope inclination angle grows, and because the sudden flight time is long, a velocity increase under the flight grows.

When the falling rock collides with the slope, it decelerates. It is because the shear failure or plastic deformation and energy are consumed in the collision as for the ground. The deceleration is large when the direction of the collision is vertically near the ground line.

d) Mass dependency at velocity

The keep abreast of velocity of rockblock after the tree is deforested is classified into three kinds of mass and Figure 12 is shown. The velocity tends to quicken by mass large. It is thought that the purpose is not to receive resistance from gravel included in the talus cone easily when the diameter of the falling rock is large.

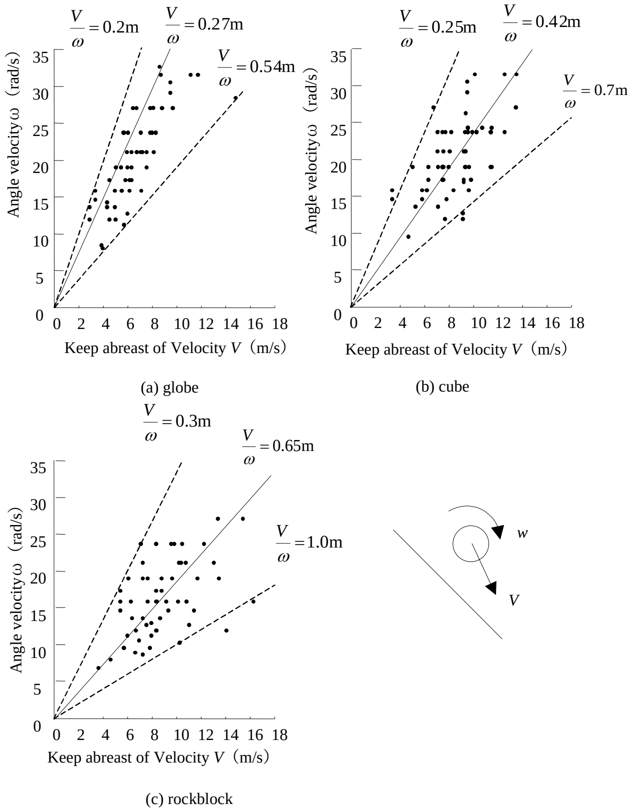


Figure-15. Relation between keep abreast of velocity and corner velocity

e) Perpendicular direction velocity and tangent direction velocity

Figure 13 shows perpendicular direction element v2 and tangent direction element u2 at the beginning flight velocity after it collides. The upper bound of v2 is 5m/s, and the upper bound of u2 is 15m/s.

The fall amount is and there is three data for the tangent direction velocity to exceed 15m in about 35-40m. The velocity is large because the angle of incidence when colliding is large though it is a talus cone. As for the velocity attenuation after it collides, the angle of incidence is controlled. It collides to steal the slope when the angle of incidence of the falling rock is big. Then, because the drag that it receives from the slope is small, the velocity change is small.

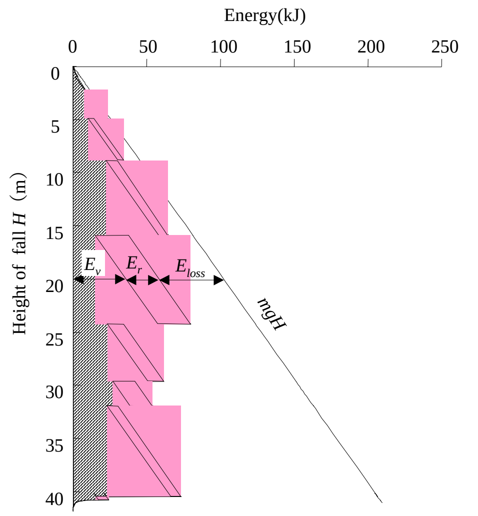


Figure-16. Change in energy of falling rock (After deforesting the tree. Cubic block)

f) Beginning flight angle after it collides

Figure 14 shows the beginning flight angle α measured from the line where the beginning flight point was connected with the landing point.

The average of all data is 22°, and standard deviation is 12° though some differs according to the falling rock shape.

g) Influence that tree exerts at keep abreast of velocity

It compares before the tree is deforested with the landing velocity after it deforests it and it shows in Table 2. From altitude 55m only to talus cone slope below there is tree. Then, the velocity that appeared on the talus cone slope is compared.

The average velocity after it deforests it is 1.04 before it deforests it when seeing on the entire slope, and 1.08 times in

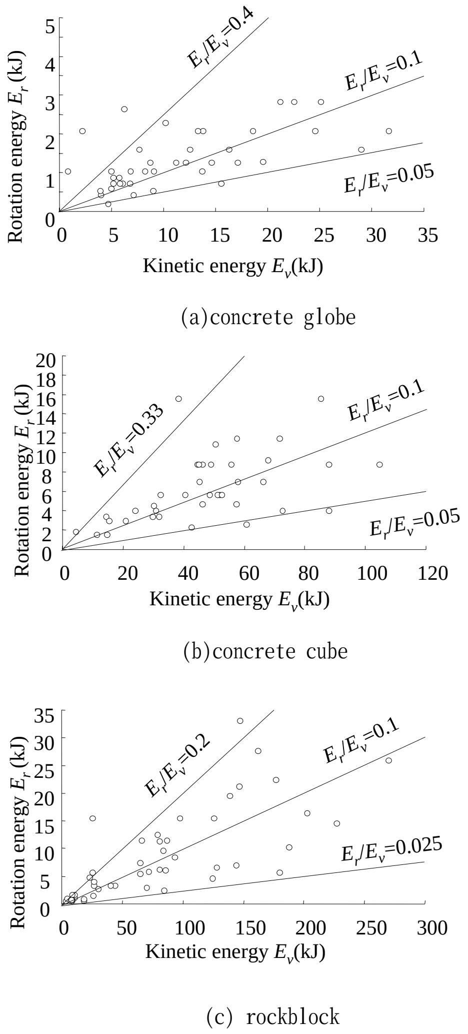


Figure-17. Relation between keep abreast of kinetic energy and rotation energy

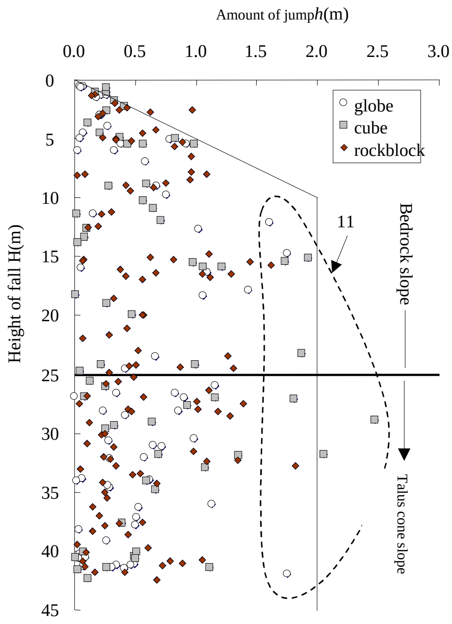


Figure-18. Amount of jump of falling rock

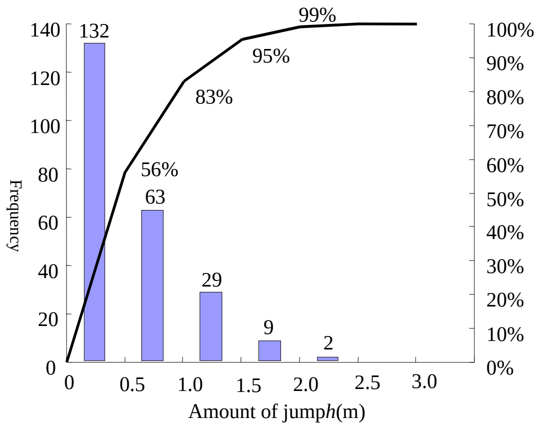


Figure-19. Histogram of amount of jump

the talus cone slope. The tree seems to influence it. However, it is thought that this is because topsoil on the bedrock disperses by repeating the experiment and the bedrock outcrop extended.

When the falling rock collides with the tree, it decelerates. However, it decelerates when colliding with the ground. They are similar.

(3) Angle velocity

Figure 15 shows the relation between keep abreast of velocity V and angle velocity ω (The falling rock under the flight requests the made number of scenes by the half rotation or 1 rotation reading it from the video image).

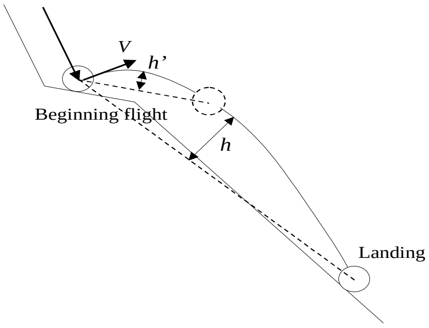
The value of V/ω is 0.2-0.54m the globe, 0.25-0.7m the cube, and has rockblock in the range of 0.3-1.0m.

The falling rock beginning flight after doing the gyration around the contact point when the slope collides. In radius r of the gyration, a concrete ball is 0.27m, and the cube is 0.42m. When the specific gravity is converted into the cube to which mass is equivalent as 2.6, lockblock is r=0.26-0.65m.

The experiment result of the globe, the cube, and the lockblock are roughly corresponding to theory value V/ω=r in which whether it was a contact point was assumed to beginning flight without slipping while rotating when colliding.

(4) Kinetic energy

Figure 16 shows the change in the energy of a cubic block of the experiment case shown in Figure 9 and Figure 12. Energy increases proportionally because potential energy mgh changes to kinetic energy Ev while flying. The ground transforms the shearing destruction or plasticity when colliding with the slope and a kinetic energy part disappears. Whether gyration energy E_r increases or decreases is decided in the direction where the drag received from the slope acts. Figure 17 shows the relation between gyration energy $E_r(=1/2I\omega^2)$ and kinetic energy $E_v(=1/2mV^2)$. The density is



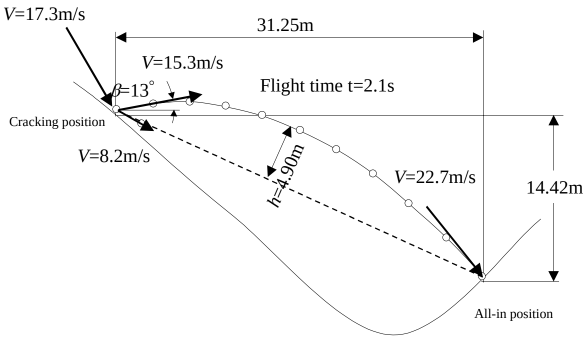


Figure-20. Beginning flight from gentle inclination part   Figure-21. Flight movement of cracking concrete ball

converted into the cube to which mass is equivalent as 2.6t/m3 and moment of inertial I of rockblock is requested.

It is roughly E_r/E_v=0.1 compared with which rotation energy of the globe, the cube, and rockblock, and it agrees to the value indicated in the falling rock measures handbook. However, E_r/E_v decrease along with not constancy but the flight so that E_v may increase though E_r doesn't change while flying.

(5) Amount of jump

Figure 18 shows the relation between amount h of the jump and the fall amount obtained by expression (2). It increases by 10m in fall height along with the height of the fall when the envelope curve of the amount of the jump is drawn. However, the tendency to become stagnant 2m when the fall amount exceeds it by 10.0m is shown. The amount of the jump shows about 1m when growing more than 35m in fall height. It is thought the influence by gentle piling up of the talus cone below from 25m in fall height, and a slope inclination.

Figure 19 shows the histogram of the amount of the jump. As for 95 percent of 235 data, the amount of the jump was lower than that of 1.5m. Moreover, 99 percent was lower than 2.0m. In the maximum value of the amount of the jump, the globe is 1.75m, the cube is 2.48m, and rockblock is 1.82m. The jump of 1.5m or more appears when colliding with the projection part of beginning flight from the gentle inclination part and a stump and the rock.

The amount of the jump measures h shown in Figure 20. As for the falling rock for the amount of the jump to exceed 1.5m, h' based on a slope inclination of the beginning flight point was 1m or less. When a slope inclination has changed, the amount of the jump is influenced by slope geometrical shape as shown in Figure 20. Then, it is necessary to note it because it doesn't have a physical meaning. A concrete ball collided with the bedrock only one time while experimenting, it cracked to two, and the flight shown in Figure 21 appeared. A part of the rotation energy changes into the kinetic energy because moment of inertial decreases when the falling rock is divided. In addition, it is thought that energy concentrates on one of falling rocks, the speed is increased, and an abnormally long jump was generated.

5.Summary

Rockblock and concrete ball and a concrete cube where the accelerometer was buried from the slope of the average inclination about 40 degrees that consisted of the bedrock and the talus cone and about 45m in height were dropped, and the movement was observed. The following finding was obtained as a result.

①As for the falling rock movement, the repetition of the flight and the collision is independent.
②The cube of the extension to the right and left when falling is larger than that of the globe.
③The inclination of the slope is fast the beginning flight speed, large the beginning flight angle from the slope, and quickens, and the sudden flight time is long, and the landing velocity quickens.
④When the mass of the falling rock is large, the velocity attenuation is small.
⑤The ground transforms the shearing destruction or plasticity when the falling rock collides with the slope and energy is dispersed. Therefore, the limit value decided because of a slope condition exists at the beginning flight velocity.
⑥The effect of the tree of the velocity attenuation was not able to be confirmed by this experiment.
⑦The relation between angle velocity ω and keep abreast of velocity V of the falling rock of r in the radius is roughly shown with ω=V/r.

⑧It is roughly 0.1 though (Er/Ev) compared with the rotation energy changes while flying.
⑨95 percent was 1.5m or less in amount of the jump of the falling rock, and 99% was 2m or less. There is a possibility that a long jump appears when the falling rock cracks when beginning flight from the inclination change point of geographical features or colliding with the projection of the stump and the bedrock.

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