Slope Stability Engineering, Yagi, Yamagami & Jiang © 1999 Balkema, Rotterdam, ISBN 90 5809 079 5

Study of accidents caused by rockfall in Kochi Prefecture

T. Ushiro, Y. Matsumoto & N. Akesaka
Daiichi Consultants Company Limited, Kochi, Japan

N. Yagi
Ehime University, Matsuyama, Japan

ABSTRACT: This report aims at evaluation and study the critical behavior of rockfall situated along the roads in the mountainous region. There are approximately ten traffic accidents caused by rockfall in Kochi prefecture every year. Three of them are fatal accidents resulting in death of the drivers and passengers. A field analysis is carried out by studying the geology and tracing the path of rockfall. The motion of rockfall is analyzed based on the data gathered in the field as well as from experiments. The obtained results from the field studies and experiments are compared and the effects of trees on the rockfall motion are evaluated and discussed.

1 INTRODUCTION

The total area of the Kochi Prefecture, shown in Fig. 1, is 7,107km^2 and its 84% is covered by mountains. The total length of roads in Kochi prefecture is 12,615km consisting of 1,074km national road, 1,063km regional road, 964km prefectural road and 9,515km local road. These roads mainly pass through the steep mountainous region where only 39% of them are improved. The Kochi prefecture, with annual precipitation of 2,600mm, is one of the most heavily rained regions in Japan. Its average monthly precipitation during the rainy and typhoon season exceeds 300mm.

Because of the climate and geography of the region, many rockfall accidents and incidents have been reported every year. In what follows some important of them will be analyzed and discussed.

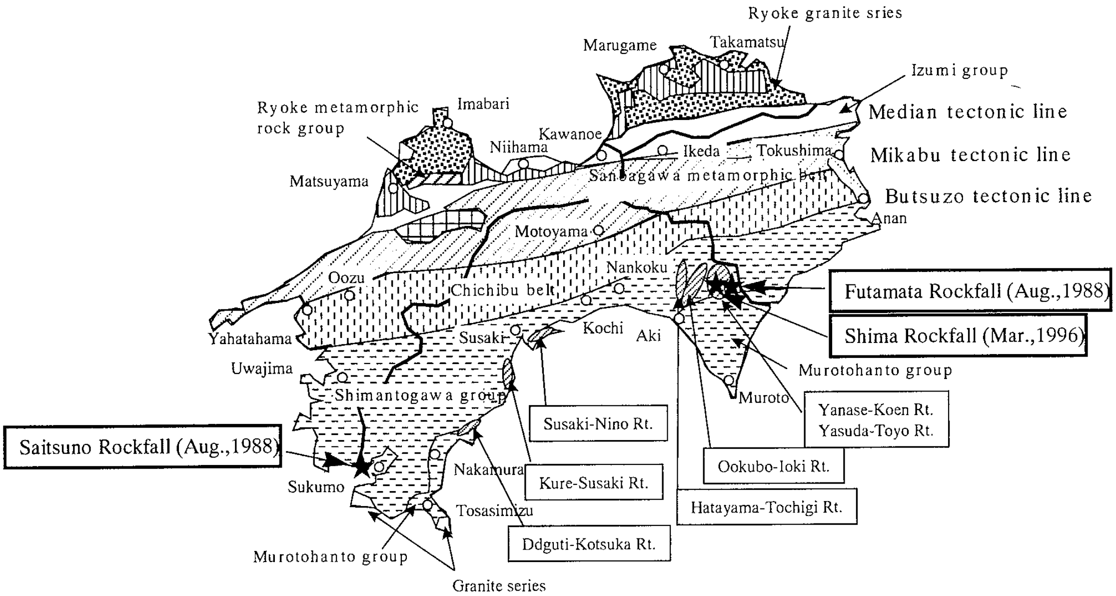

Fig.1 Locations of Accident by Rockfalls in Kochi Prefecture

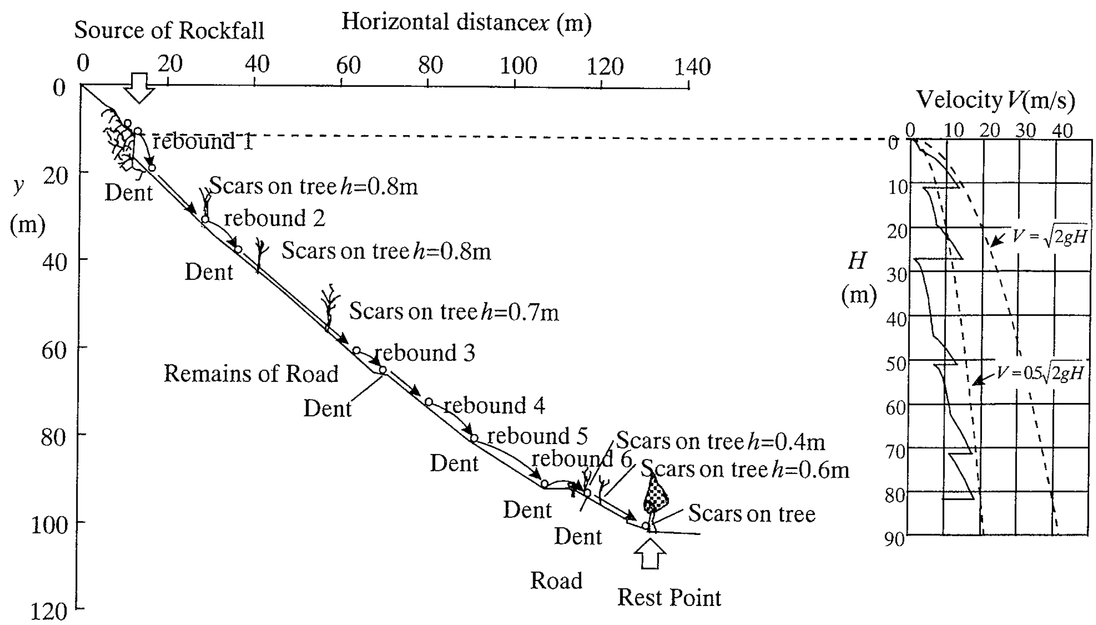

Fig.2 Shima Kitagawa Rockfall

2 SHIMA ROCKFALL (SHIMA, KITAGAWA)

2.1 *Overview*

At 7:50 am of Mar. 2, 1996, a rockfall of approximately 10 tons hit a car running on the Toyo-Yasuda prefectural road (Route 439). The driver was injured and died after being rushed to the hospital.

The topography of the site is a valley, where the steepness of the slope is 41° up to remains of the road at the height of 25m from the road surface and 36° for the higher points, see Fig. 2.

The geology of the site, which falls into the Shimantogawa group, consists of sandstone and shale. The bedrock is exposed and formed scarp face of 80m above the road. There are many boulders of 0.5～0.8m on the talus slope between the roads and the remains of the roads. Vegetation of the slope is a broadleaf tree of 45 years old. There are also 25～29 years old cedars above the scarp face.

2.2 *Source of rockfall*

The sandstone block caused the accident had size of 2.6m×1.3m×1.8m (with an estimated weight of 10 tons). It was rested against a cedar tree 18m away from the road.

The source of rockfall was scarp face of 82m above the road and there was evidence that the rock had loosened from it, see Fig. 3. The bedrock was

Fig.3 Source of Rockfall

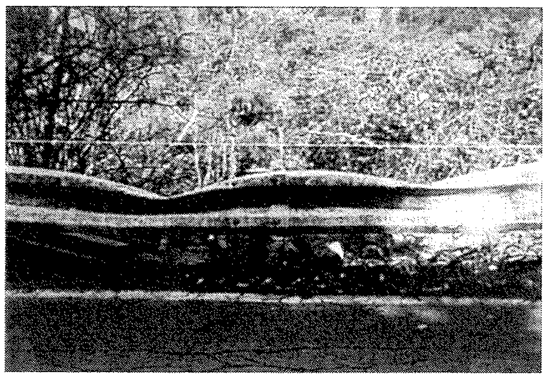

Fig.4 Deformation Caused by Rockfall

fractured and had open cracks on its surface. The deformation caused by the rockfall is shown in Fig. 4.

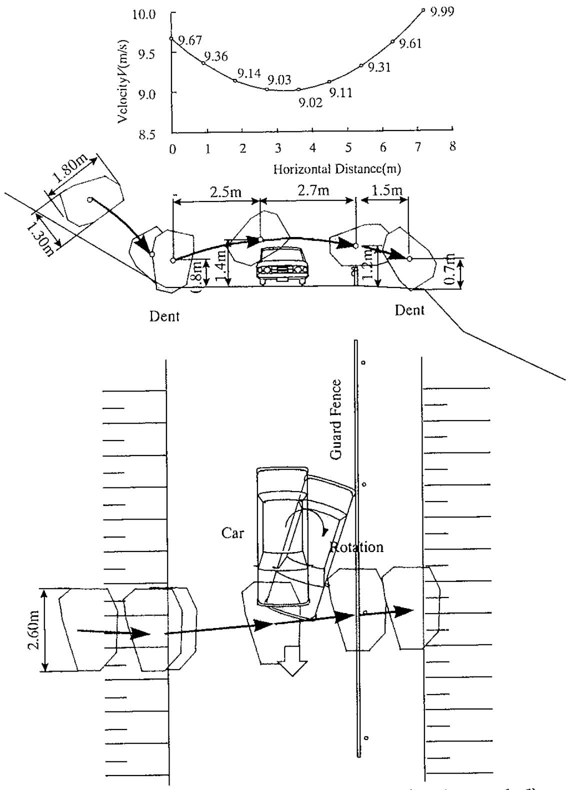

Fig.5 Rockfall Accident Diagrams (Rebound 6)

2.3 *Mechanics of rockfall motion*

Many scars, splits, and shear failure were found on trees along the path. These scars were located less than 1.0 m above the root of the trees. Also 6 dents caused by rockfall were found. A guard fence had been installed along the side of the road and the

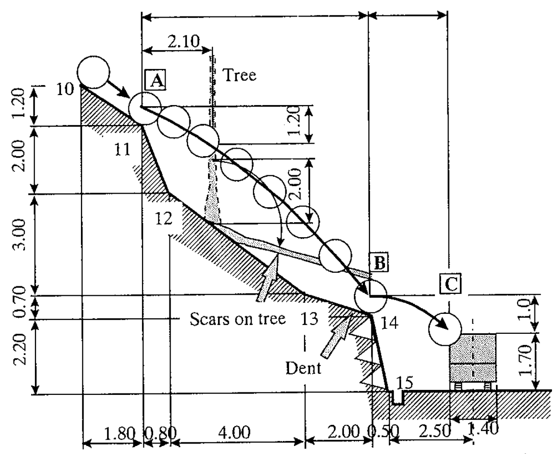

Fig.6 Flight Path of Rockfall (Futamata,Kitagawa)

props of the fence were pushed into the ground by 13cm by the impact of rockfall. The beams of fence were deformed to W shape, which matches to the bottom shape of the boulder. This indicates that the boulder jumped over the fence.

There were no slip marks left on the road. Therefore, the boulder hit the running car before the driver could push the break. Impact of the rock on the right side of car at the head-light rotated the car clock wise and left the tail of car hit to the guard fence, see Fig. 4. Figures 2 and 5 show movement of the rockfall estimated from traces and tracks.

3 FUTAMATA ROCKFALL (FUTAMATA, KITAGAWA)

3.1 *Overview*

At 8:20 am of August 11, 1988, a boulder with an estimated weight of 1.0 ton hit a pickup truck running on the Toyo-Yasuda prefectural road (Route 439). The boulder crushed and killed the driver's wife sitting next to the driver. The driver was seriously injured and hospitalized for 2 months. It was raining at the time of accident. That is, the rock was loosened due to the rain, which was considered the cause of accident.

The geology of the site is Southern Shimanto belt, which consists of sandstone and shale. The slope was covered with 1～2m thick residuals. There were many 0.3m～0.5m boulders on the slope. However, boulders of equal sizes located only over 47m above the road caused the accident. The source of rockfall was 47.6m above the road. There was a scarp face supplying boulders above 20m of the source.

The average steepness of the slope up to 18.1m above the road, where remains of the road existed, was 49°. The average steepness between the remain of road and the source was 41° and it was steeper for higher points. The average steepness between road and the source was 44.° Vegetation of the slope was broadleaf trees for between road and remains of the road. The slope above remains of the road was a forested area consisting of cedars trunk having size of 30cm.

3.2 *Mechanics of rockfall motion*

The boulder that hit the truck was angular sandstone boulder having size of 1.0m × 0.7m × 0.55m and estimated weight of 1.0 ton. This boulder left scars on trees along the path. Most scars on the trees were left within 1.1m above ground.

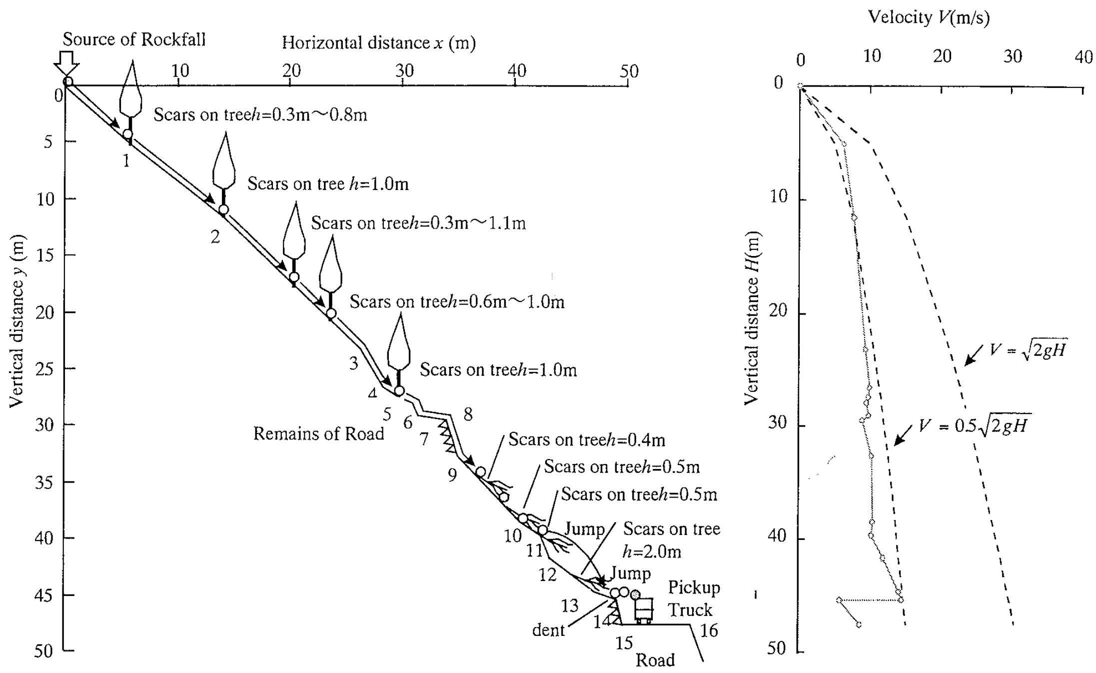

Fig.7 Cross section of Futamata Rockfall Slope

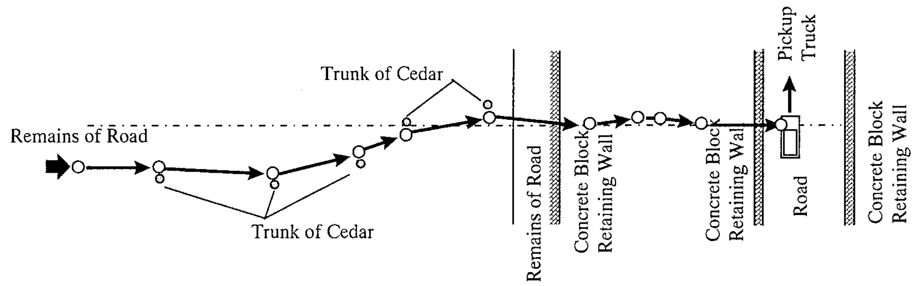

Fig.8 Path of Rockfall

From traces of the rock, it is estimated that the boulder initially rolled or slid on the slope, then jumped at point 11, bounded on the retaining wall, and finally hit the roof of car. There was no dent and therefore no jumping till point 11.

The estimated rockfall path is shown in Fig. 8. The site slope has no significant change and its contour lines are nearly parallel. Therefore, rockfall moved straight but was deflected by trees.

4 SAITSUNO ROCKFALL (SAITSUNO, OTSUKI)

4.1 *Overview*

At 2:20 p.m. on August 12, 1988, a boulder caused by landslide hit a car running on Route 321. The boulder broke through the windshield, hitting steering wheel, passing through side of the driver's head, hitting a passenger's head on the left rear seat, and escaped from rear window. The passenger was killed instantly and the driver was seriously injured. There was a heavy rain earlier in the morning, and it loosened the slope and caused landslide and rockfall.

The geology of the slope, with Southern Shimanto formation, consists of sandstone and shale. Its steepness is approximately 53°. Although the slope was densely vegetated by cedars, the boulder passed through sparsely vegetated previous debris.

There was a rockfall prevention work in the site, but there was no prevention work at the location of accident. The reason was probably due to existence of a 5m space between the road (with 3.7m width) and mountain which has given false sense of safety.

4.2 *Mechanics of rockfall motion*

There were evidences of exfoliation of boulder in the previous debris at 48m above the road, thus this place was considered as source of the rockfall. There were eight sandstone boulders of size 0.5m×0.3m×0.2m and many boulders with diameters of 0.05m-0.1m in the site. It was concluded that exfoliated boulder disintegrated along the way down on the slope or on the road upon impact. There were broken and scared trees at the passage of rockfall and remains of impact of rockfall were left on the slope. We concluded that rockfall rolled from source, rebounded and rolled on the remain of road, hit retaining wall and jumped, finally hit the car as shown in Fig. 9. It is estimated that the final rebound velocity to be 10.0 m/s and impact velocity to the car to be 12.1 m/s.

5 CHARACTERISTICS OF ROCKFALL ON SLOPES

5.1 *Velocity conservation coefficients of rockfall*

Figure 2 and Figure 5 shows the estimated velocity of rockfall. We estimated the flight path of rockfall and calculated velocity from 3 points of flight path while rockfall was in the air. We also estimated coefficient of friction on the slope to be μ=0.5 and resistance of the slope to be C_k, which was constant throughout the slope. We calculated C_k under the conditions of zero initial velocity and no change in velocity when the rockfalls motion changed from a linear (slide or roll) state to a nonlinear (rebound) state. The estimated velocity of the rockfall can be given by the equation 1 as follows:

$$\tan\theta > \frac{7}{2}\mu$$

$$V = \frac{g}{C_k}(\sin\theta - \mu\cos\theta) + \left\{V_0 - \frac{g}{C_k}(\sin\theta - \mu\cos\theta)\right\}e^{-C_k t}$$

$$\tan\theta \le \frac{7}{2}\mu$$

$$V = \frac{5g}{7C_k}\sin\theta + \left\{V_0 - \frac{5g}{7C_k}\sin\theta\right\}e^{-C_k t} \qquad (1)$$

(g = acceleration of gravity, θ = slope angle, t = time) The velocity conservation coefficients $\alpha_v = V/\sqrt{2gH}$ for calculated velocity was α_v = 0.5 for Shima and Futamata, and α_v = 0.75 for Saitsuno.

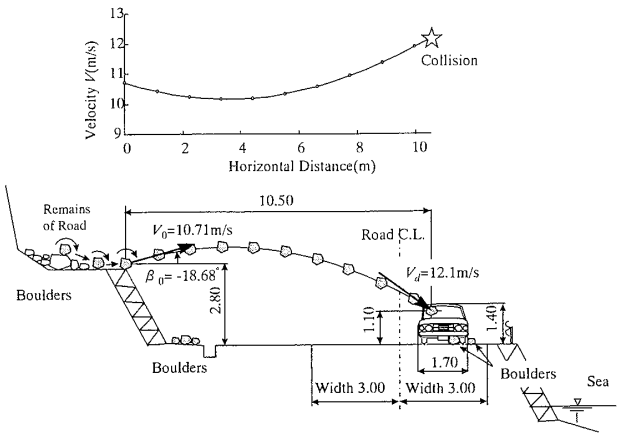

Fig.9 Flight Path of Rockfall (Saitsuno,Otsuki)

Figure 10 shows relationship between velocity conservation coefficient α_v and steepness of slope. Data for this figure includes actual rockfall (Kitanada, Ooto) and field rockfall experimental data. All the field experiments were performed on slopes without vegetation cover for easier observation.

When the slope was talus, velocity conservation coefficients of actual slopes were 25% smaller than experimental slopes. This could be the effect of trees. There was no difference in velocity conservation coefficient between actual and experimental slopes for rock slopes. This is because there was less trees on rock slopes thus energy loss by trees was smaller.

5.2 *Rebound height of rockfall*

Figure 11 shows relationship between estimated rebound height from scares on trees and steepness of slope. Data for this figure includes actual rockfall (Kitanada, Ooto) and field rockfall experimental data. We used maximum rebound height in actual slopes, reduced 95% of average for confidant rebound height in experimental slopes.

The rebound heights of actual slopes were 1.0m smaller on talus and 1.5m smaller on rock surface than experimental slopes. This can be explained by energy loss by trees.

6 CONCLUSIONS

From analysis of actual and experimental data, the following conclusions can be drawn from this study:

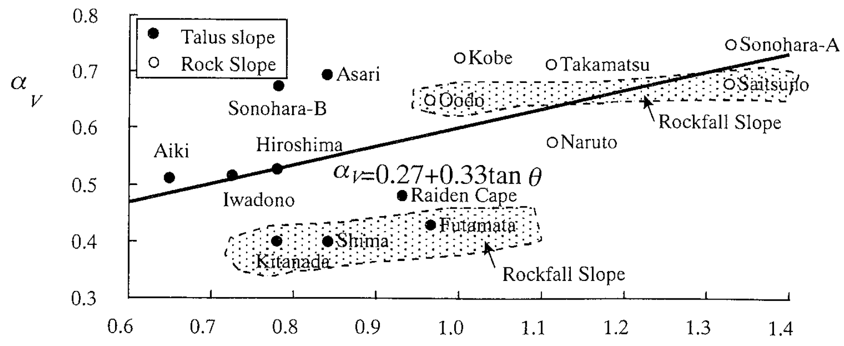

Fig.10 Relationship between Velocity Conservation Coefficient and Steepness

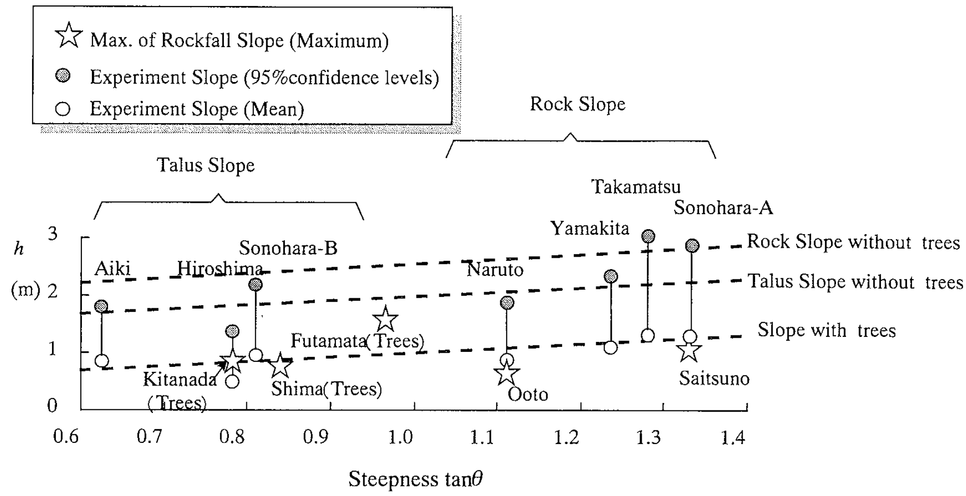

Fig.11 Relationship between Jumping Height and Steepness

1. Actual rockfall slopes had trace of rockfall on trees and surface based on which the rockfall motion can be estimated.
2. Rockfall velocity on actual slope was 25% smaller than the experimental data. This is resulted by energy loss caused by trees.
3. Rebound heights of the actual slopes were 1.0m smaller on the talus slope and 1.5m smaller on the rock slope than those of the experimental slopes. This can be explained by energy loss caused by trees.
4. If there is a flat area such as remain of road on slope, it acts as a jump stand and increases rebound height. That is, it increases the danger.

7 REFERENCES

Investigation Committee of Rockfall Accident on Toyo-Yasuda Prefectural Road. 1996. *Report of rockfall accident investigation.*

Japan road society.1983. *Rockfall measure handbook.* (In Japanese)

Management office of Oodo dam. Ministry of Construction. 1996. *Report of rockfall accident investigation.* (In Japanese)

Public Works Research Institute .1980. *Report of field rockfall experiment.* (In Japanese)

Sasaki Y, Taniguchi E, Funami K, Tanimoto M Horiguchi M . 1981. Experiment of rockfall jumping height.*14th Journal of Japan Road Society Meeting.*

Ushiro T, Murakami,T. 1983. Estimation rockfall jumping hight. *Journal of the symposium about rockfall impact force and design rockshade. Vol.1 .pp48-54.* (In Japanese)

Yoshida H., Ushiro T., Masuya H., Fujii T., 1991. Evaluation the impact force on rock shade considering slope characteristic. *J. of structural mechanics.*Vol.37A. pp1603-1616 (In Japanese)