一般共同研究
２０２２Ｇ－０１

京都大学　防災研究所
Disaster Prevention Research Institute
Kyoto University

火山噴火時の噴石の飛散性状の解析－予測手法の開発

Analysis of scattering properties of cinders during volcanic eruption

— Development of forecasting methods

令和６年４月

April, 2024

研究代表者　　内 田 孝 紀
Coordinator　Takanori UCHIDA

報　告　書

令和　６年　４月３０日

一般共同研究

（ 課題番号：2022G-01 ）

［申請者（研究代表者）］
氏　　名　：内田　孝紀
職　　名　：教　授
所属機関名：九州大学　応用力学研究所

課題名：　火山噴火時の噴石の飛散性状の解析－予測手法の開発
研究代表者：　内田　孝紀
所属機関名：　九州大学　応用力学研究所
所内担当者名：　丸山　敬
研究（滞在）期間：令和５年４月１日　～　令和６年３月３１日
研究（滞在）場所：　九州大学応用力学研究所および京都大学防災研究所
共同研究参加者数：　４名（所外２名，所内２名）

研究代表者	内田　孝紀	九州大学・応用力学研究所	教授	男性
所内（防災研）担当者	丸山　敬	京都大学・防災研究所	教授	男性
研究分担者	井口正人	京都大学・防災研究所	教授	男性
研究分担者	竹見哲也	京都大学・防災研究所	教授	男性

研究及び教育への波及効果について

火山噴火時の噴出物の飛散・拡散挙動を解析・予測する手法を構築するとともに、検証用のデータを得るための実験法・実験装置を開発した。これにより、火山災害に対する、地域防災計画、広域避難計画の策定、また、防災教育に対して有用な資料の提供が期待できる。

(1)目的・趣旨

噴石や火山灰の飛散範囲、火山ガスの濃度分布の予測を行い、ハザードマップ等の作成に活用して、火山災害の防災・減災対応策の実効性向上に貢献するため、火山噴出物の飛散・拡散性状の解析・予測手法の開発を行う。これにより、地域防災計画、広域避難計画の策定、また、防災教育に対して有用な資料を提供する。

(2)研究経過

火山噴火時に放物運動を行う“大きな噴石”、風に流され、飛散範囲や落下速度が風速や噴石の形状の影響を受けて変化する”小さな噴石”、さらに、拡散運動を行う粒径の小さな火山灰や火山ガスに至る火山噴出物の飛散・落下モデルの構築を以下のように行った。

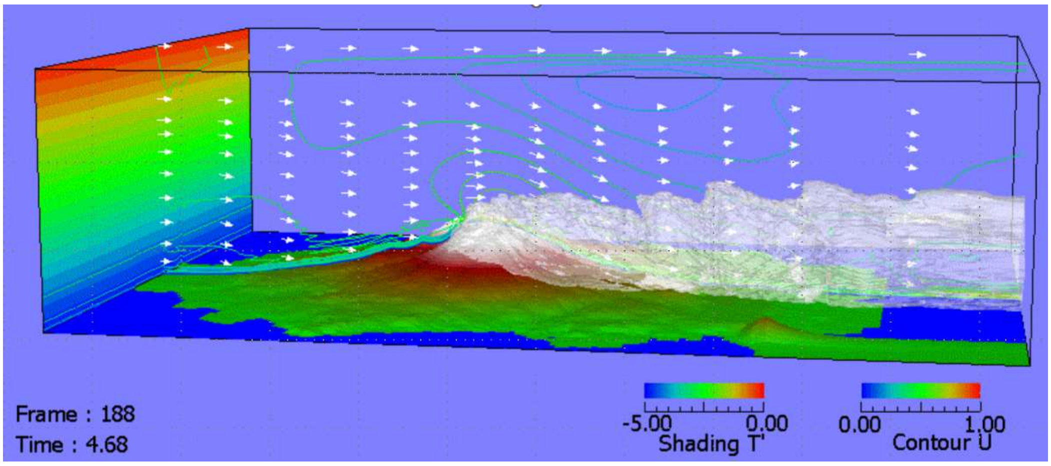
令和４年度には、広域の気象場から火口付近の詳細な乱流場までを接続しながら解析するため、広域の気象場はメソスケールモデル WRF により求めた。火口付近の詳細な気流場は広域の気象場を境界条件として取り込み、火山ガスの噴出・拡散に関して、高浮力流の解析が可能な“低マッハ数近似モデル”を用い、大気と組成・物性の異なる火山ガスの影響をより正確に取り込むことのできる計算手法を検討した。

令和５年度には、火山噴出物である噴石の飛散・落下モデルを作成した。また、風洞実験および衝撃試験装置を用いた噴石の空力・熱伝達特性の計測、および、リスク評価のための噴石の建物外装材への衝撃試験を行った。

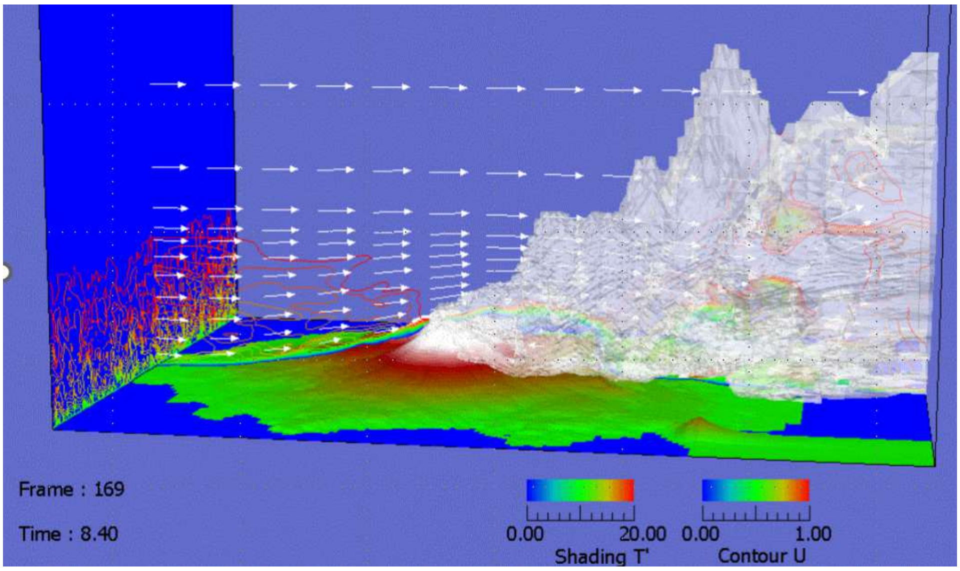
(3)研究成果

１．気流場の解析について

　噴火時の火山周囲の気流性状を、メソスケールモデルを用いたWRFにより求めた広域の気象場から、火口付近の詳細な乱流場までを接続しながら解析する手法を開発した。火口周辺のより詳細な解析のために、地形の凹凸、地表面粗度の影響を取り込むキャノピーモデルを組み込んだラージエディシミュレーションを用いて乱流場の計算を行えるようにした。



桜島周辺の噴煙のシミュレーション：安定時
流入風速0.5m/s（1/7勾配、乱れなし）、温度（＋勾配：-5K～0K）、噴流：温度+20K、0.2m/s



桜島周辺の噴煙のシミュレーション：中立時
流入：風速1m/s, 0.5m/s　(1/7勾配、乱れなし・あり)、温度（勾配0)、噴流：温度+20K、0.1m/s

２．火山ガスの噴出・拡散解析について

火山ガスの噴出・拡散に関して、高温熱流場の解析に用いられる“低マッハ数近似モデル”を用いた１方程式系のラージエディシミュレーションによる基礎方程式の定式化を行った。

質量保存：
$$\frac{\partial\rho}{\partial t}+\frac{\partial\rho\tilde{u}_j}{\partial x_j}=0$$

運動量保存：
$$\frac{\partial\rho\tilde{u}_i}{\partial t}+\tilde{u}_j\frac{\partial(\rho\tilde{u}_i)}{\partial x_j}=-\frac{\partial}{\partial x_i}\left(\hat{p}+\frac{2}{3}\rho\tilde{K}\right)+\frac{\partial}{\partial x_j}\left\{2\rho(\nu+\nu_{SGS})\tilde{D}_{ij}\right\}+\rho g_i\delta_{i3}$$

エネルギー保存：
$$\frac{\partial\rho\widetilde{C_p}\theta}{\partial t}+\tilde{u}_j\frac{\partial(\rho\widetilde{C_p}\theta)}{\partial x_j}=\frac{\partial^2}{\partial x_j}\left\{\left(\lambda+\rho C_p\frac{\nu_{SGS}}{Pr_{SGS}}\right)\tilde{\theta}\right\}+Q$$

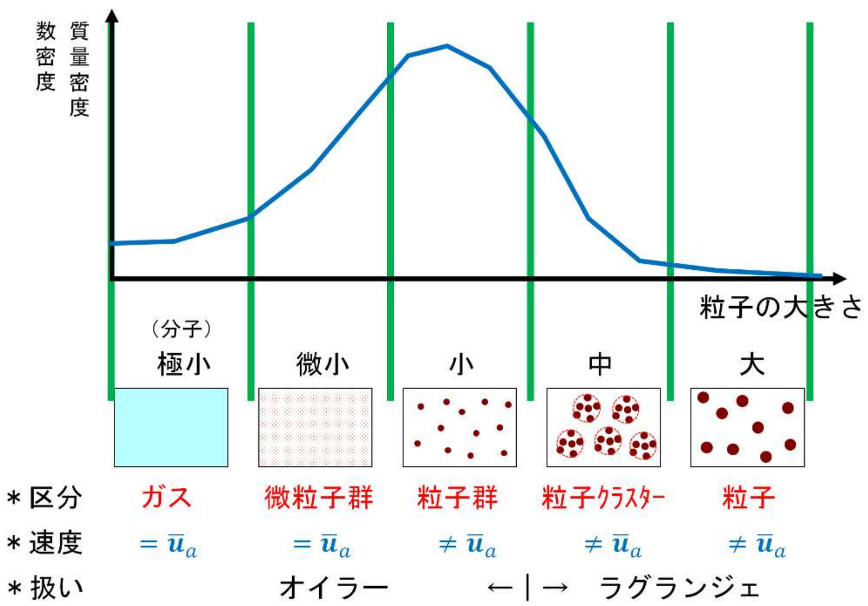
状態方程式：
$$p_0=R\rho\tilde{\theta}$$

SGS乱流エネルギー：
$$\frac{\partial\rho\tilde{K}}{\partial t}+\tilde{u}_j\frac{\partial(\rho\tilde{K})}{\partial x_j}=\rho\left(2\nu_{SGS}\tilde{D}_{ij}-\frac{1}{3}\tilde{K}\right)\tilde{D}_{ij}-\rho\frac{C_D\tilde{K}^{\frac{3}{2}}}{\tilde{\Delta}_\varepsilon}+\rho\frac{\partial}{\partial x_j}\left(\frac{\nu_{SGS}}{\sigma_k}\frac{\partial\tilde{K}}{\partial x_j}\right)$$

低マッハ数近似により導かれた方程式に、フィルタリングを施して求めたLES 型の方程式系

３．噴石・火山灰の飛散について

火山噴出物である”大きな噴石”から”小さな噴石”、火山灰について、形状、粒径、密度、速度等に対する空力特性の変化､熱伝達特性の変化を考慮した飛散粒子として気流計算に組み込む物理モデルを作成した。

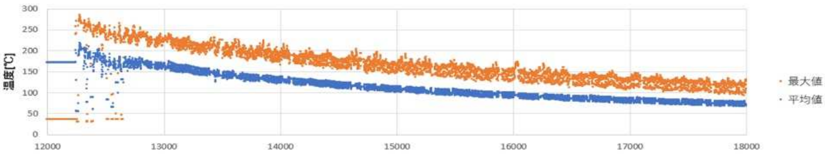


噴出物の大きさとその扱い

４．実験および検証用データの取得

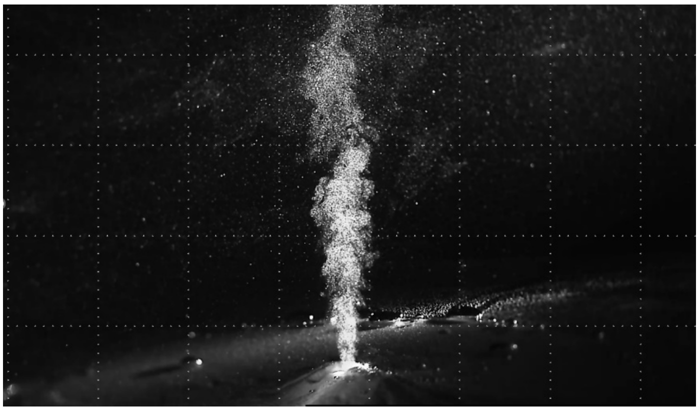
作成した解析手法の適用性と精度検証を行うためのデータを得るため、大気と噴石の熱伝達特性を明らかにする風洞実験、密度流れの再現ができる水槽を使った実験装置を開発した。

加熱した噴石を風洞内につるして風をあてる



噴石の表面温度の変化

風洞内に加熱した噴石をつるし、風を吹かせて表面温度の変化をサーモグラフで明らかにする実験



水槽内に設置した火山模型の噴火口から噴出する密度流れを、
PIV（Particle Image Velocimetry）により、流速分布を計測する実験

また、衝撃試験装置を用いた噴石に対する建物外装材の耐衝撃特性を明らかにし、噴石衝突時のリスク評価のための基礎資料を得た。研究報告として公表→付録に添付する。

(4)研究成果の公表

噴石に対する建物外装材の耐衝撃特性に関して　「Maruyama,T.　and　Iguchi,M.,　Impact Resistance Test of Cladding by Using Gravel, Journal of Disaster Research Vol.18 No.8, 2023」(出版物を添付) として発表した。(付録に添付)

－ 付録 －

https://doi.org/10.20965/jdr.2023.p0918

Survey Report:

Impact Resistance Test of Cladding by Using Gravel

Takashi Maruyama*,† and Masato Iguchi**

*Disaster Prevention Research Institute (DPRI), Kyoto University
Gokasho, Uji-shi, Kyoto 611-0011, Japan
†Corresponding author, E-mail: maruyama.takashi.8w@kyoto-u.ac.jp
**Volcano Research Center, Kyoto University, Kagoshima, Japan

[Received June 28, 2023; accepted August 25, 2023]

Multiple reports have emphasized the significance of protecting cladding from windborne debris or falling cinders during strong winds or volcanic eruptions. Japan has no available building codes or standards for protecting the cladding against the windborne debris or falling cinders. In contrast, certain specifications for cladding performance when impacted by windborne debris, along with associated testing methods, are outlined in American, ISO, and JIS standards. A series of impact tests was conducted on selected specimens, like cladding used for residential projects, to evaluate their impact resistance performance. This study presents the outcomes of the impact performance tests, including their destruction modes, for representative materials of cladding like float glass, Japanese tiled roof, batten-seam roof, and slate-tiled roof. The tests were conducted using an air cannon as the gravel-propulsion device. The impact-resistant speed corresponding to the mass of gravel was clarified for the specimens.

Keywords: impact resistance test, cladding, gravel, windborne debris, falling cinders

1. Introduction

During strong wind disasters, like typhoons or tornadoes, cladding is often torn apart or stripped away, thus resulting in flying debris of various sizes. Numerous reports attest that such debris collide with other buildings, setting off a chain reaction of debris production and aggravated damage. Additionally, damages caused by volcanic cinders and small gravels carried by the wind over long distances result in their descent upon buildings, causing extensive damage to cladding elements like roofing, walls, and window glass. Particularly, Sakurajima has recorded 173 cases of gravel-fallings at its base triggered by Vulcanian eruptions from Mimamidake crater since 1955. These gravel-falls occurred at a location approximately 20 km away from the crater. The gravel disperses to distant areas when volcanic plume rises high or strong winds blow. Among 173 cases, 86 reported damages, mainly to vehicles, buildings, and aircrafts. Usually, in buildings, roofing materials like roof tiles and slates are most commonly damaged. One case reported damage to the glass component of a solar water heater [1].

Damage to the cladding permits rain and wind to enter the building. This damages the interior and household items, and also corrodes the structural parts of the building like pillars. Furthermore, glass-fitted openings are the most vulnerable parts against flying debris. When these openings are shattered, the resultant glass shards pose a risk to human safety. Additionally, the broken openings can lead to an increase in indoor pressure, potentially causing damage to the roofing and other opening parts. This can result in significant damage to the entire building. Therefore, safeguarding the cladding from flying debris is important to prevent or minimize damage to the buildings.

Clarifying impact-resistant performance of cladding is the base for preventing damages from flying debris. Concerning the assessment of the impact-resistant performance of cladding against flying debris, the American Society of Civil Engineers' ASCE 7-05 [2] is a recognized standard that evaluates buildings' openings for resistance to flying debris during hurricanes. Testing methods and standards for assessing cladding performance under impact are specified in American Society for Testing and Materials' ASTM E1886-04 [3] and ASTM E1996-04 [4]. Furthermore, evaluation methods of assessing the destruction performance resulting from impact, as outlined in ISO 16932 [5], are based on the performance standard and evaluation methods introduced in the aforementioned ASTM documents. Accordingly, ISO 16932 and ASTM documents provide almost identical standards. Also, Japanese JIS R 3109:2018 [6] uses ISO 16932 as basis for assessing glass resistance performance under impact from typhoon-blown flying debris.

This study carried out impact tests with an experiment device (air cannon) [7] that was developed in accordance with ISO standard. Among the various objects that get blown during strong winds, gravel probably damages the claddings the most. Furthermore, among the various-sized cinders dispersed during eruptions, gravel flies to distant locations and damages the cladding. Thus, we used gravel as experimental missiles.

Glassed windows are the weakest in the vertical part of cladding to resist damage from flying debris. Thus, we

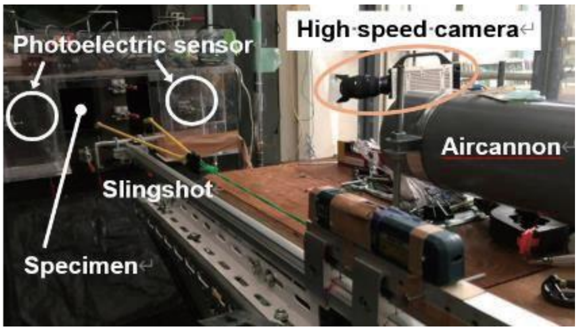


Fig. 1. Impact test devices.

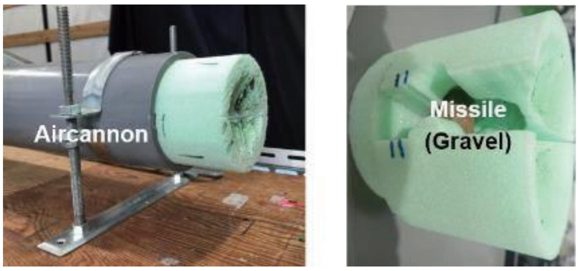


Fig. 2. Capsule enclosing missile.

used float glass, used in most windows, as an experimental specimen. We also used roofing materials widely used in Japan. The next section describes destruction modes that were found out from the impact test and discusses cladding's destruction performance by impact.

2. Experiment

2.1. Testing Device

Missiles were directed toward cladding specimens during the experiment as shown in **Fig. 1**. The specimens were positioned on a mounting jig, strategically placed in front of an injection device. A slingshot was used for a low-speed injection. For a high-speed injection, missiles were put in urethane foam capsules and injected by an air-cannon as shown in **Fig. 2**. The air-cannon can perform impact resistant tests in compliance with ISO standard. The missiles are expelled from the capsules just before collisions, ensuring that only the missiles collide with the specimens. The collision surfaces were recorded every one-10000th second with a high-speed camera triggered by missile's pass with photoelectric sensor to study collision and destruction modes, and the missiles' impact speed. See reference [7] for specifications of the testing device.

2.2. Impact Test

Missiles with various mass and speed were collided with the specimens. As impact speed increases, the specimens' damage modes escalate from "no changes observed," through "no cracks but scratches or dents," to "cracks or holes." The impact test began at a low-speed, and the impact speed was gradually increased. The test was concluded when cracks or openings were observed. In case of glass and Japanese roof tiles, the missiles were guided to impact approximately the same points. For other specimen materials, impacts were targeted at approximately the same points unless changes were noted. Upon observing the damage, the impact points were shifted by at least 10 cm away from the previous location.

Fig. 3. Gravels as impact missiles.

2.3. Impact Missiles

Gravel varies in density and solidity. We chose gravel pieces that could make high impact, thereby causing more destruction. During volcanic eruptions, pumice and rock fragment propel in the air. Lava from volcanoes coagulates in the air and becomes pumice. Rocks around volcanic craters blow up and break into pieces.

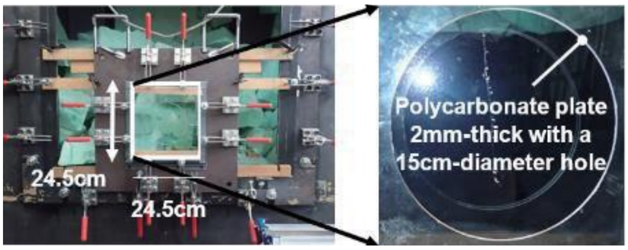
We conducted an initial test using volcanic cinders from Sakurajima. In this test, pumice, characterized by its low density and high fragility, was crushed upon impact. Although it has the ability to scratch the specimens, it failed to cause cracks or holes. Accordingly, andesite gravel collected from Sakurajima, as depicted in **Fig. 3**, was employed as missile in the impact test. The mean density of the andesite gravel was 3.0, Mohs's hardness ranged from 5.5 to 6.5, and the mass was up to about 100 g. According to JIS A 1204:2009 [8], it is categorized as "coarse gravel."

2.4. Specimens

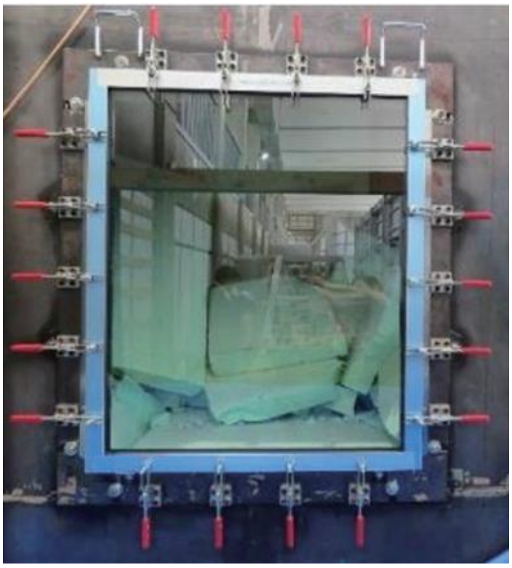
Float glass was selected as a representative specimen of cladding due to its anticipated lower impact resistance, and widespread use in opening parts. For roofing, we chose Japanese roof tiles, slate tiles, and sheet metal.

2.4.1. Float Glass

Two types of float glass specimens, "small specimens; 5 mm-thick, 30 cm $\times$ 30 cm-area" and "large specimens; 5 mm-thick, 90 cm $\times$ 110 cm-area" were used for the impact test. Small specimens were mounted on an iron frame (24.5 cm $\times$ 24.5 cm) with rubber on both sides. The frame was then set in front of the injection device vertically. A perforated polycarbonate plate was set in front of the small specimens, as shown in **Fig. 4(a)**. The holes in the



(a) Small specimen



(b) Large specimen

Fig. 4. Experimental set up for float glass.

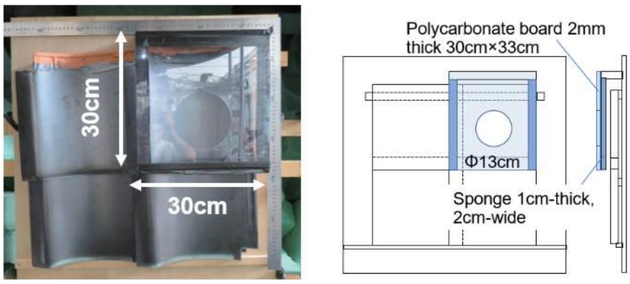


Fig. 5. Experimental set up for Japanese roof tile J-type roof tile (Marusugi disaster resistant roof tile #53 Silver Black), Base material: Lauan plywood 12 mm-thick Polycarbonate board 2 mm-thick 30 cm × 33 cm.

plate were aligned with the centers of the specimens, ensuring that the missiles would strike the central area of each specimen. The mounting and impact destruction test of large specimens, as depicted in **Fig. 4(b)** were carried out in accordance with ISO 16932.

2.4.2. Japanese Roof Tiles

Four Japanese roof tiles were arranged as they would be on an actual roof, as shown in **Fig. 5**. Similar to the float glass setup, a polycarbonate plate with 13 cm-diameter hole was placed in front of the roof tiles, allowing the missiles to target the central area of the upper-right tile.

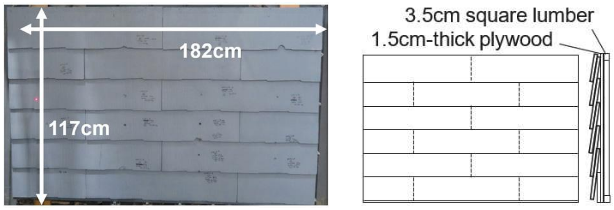


Fig. 6. Slate Tiles Roofing. Slate tile: Kmew Colonial, Base material: lauan plywood, 12 mm-thick.

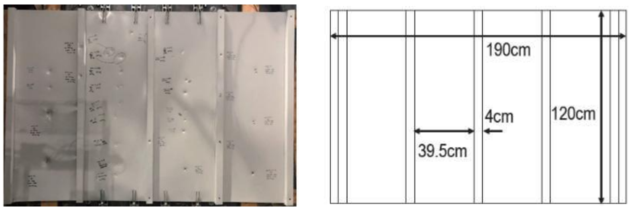


Fig. 7. Sheet Metal Roofing (Batten Seam Roofing). 0.4 mm-thick sheet metal (Tatehira #333). Base material: lauan plywood 12 mm-thick.

2.4.3. Slate Tiles

As shown in **Fig. 6**, slate tiles were installed as they would be on an actual roof. The area of the slate tiles was 117 cm × 182 cm. The points of impact were set approximately at the center of each tile.

2.4.4. Sheet Metal Roofing (Batten Seam Roofing)

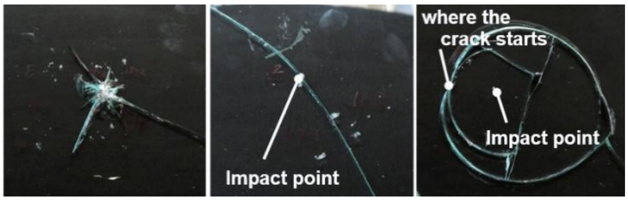
As illustrated in **Fig. 7**, 120 cm × 190 cm sheet metal (batten seam) roofing was installed to replicate an actual roof. Missiles were launched to impact somewhere along the central lines of the sheet, between two battens.

3. Destruction Modes

When missiles made contact with the specimens, no discernible differences were observed at the point of impact when the missiles had low mass or low impact speed. However, as impact speed increased, resulting in greater force of impact, the levels of destruction rose from ① to ④: ① scratches and dents that did not reach the back side of the specimen, ② cracks that reached the back side of the cladding specimen, ③ openings were formed, and ④ the missiles penetrated the specimens. In this test, the speed of ② at which cracks and openings began to form in the specimens was defined as "destruction speed," referred as V_C.

3.1. Float Glass

As shown in **Fig. 8**, breakages with Hertzian cone crack (cone-shaped damages formed on the other sides of the impact surfaces) and fractures, which formed radial and circular cracks, were observed. Cracks originated not only from the impact points but also from areas located



Hertzian cone | cracks | cracking at a point different from impact point

Fig. 8. Destruction modes of float glass.

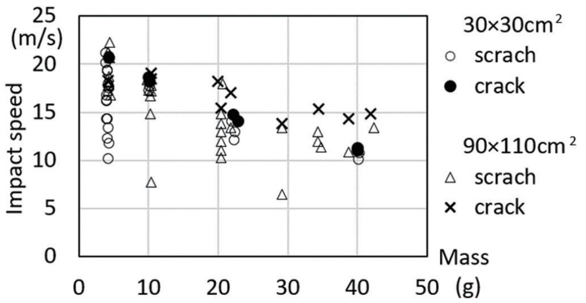


Fig. 9. The effect of missiles' mass and impact speed on destruction modes (float glass, 5 mm-thick).

away from the impact points. When a specimen was subjected to multiple missile impacts, the cracking points occasionally coincided with locations where missiles had struck previously. In such cases, it is likely that the prior missile impacts contributed to the development of these cracks.

Figure 9 shows the effect of gravel's mass and impact speed on destruction modes. The impact speed at which a visible damage occurred decreased as the mass of a missile increased. As for the damages greater than cracking, specimens' sizes did not affect the destruction velocity with small mass less than 20 g.

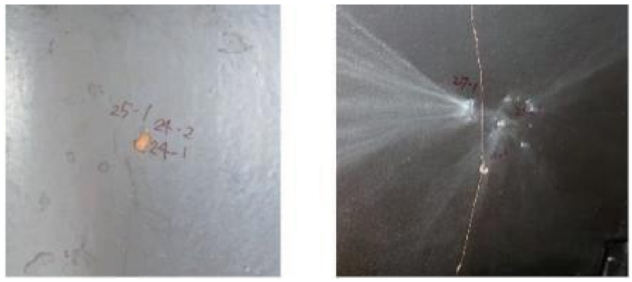
However, with an increase in the missile's mass, a slightly higher impact speed was required, particularly for larger specimen areas.

3.2. Japanese Roof Tiles

For Japanese roof tiles, while impact speed was low, the surface came off or a dent was created (**Fig. 10(a)**). As the impact speed increased, the specimens started to crack. In terms of destruction mode, as shown in **Fig. 11**, when missiles with 10 g were collided, specimens did not crack (even though scratches occurred) up to the speed of 34 m/s. With missiles of greater mass, the speed required to cause destruction became lower.

3.3. Slate Tiles

For slate tiles, scratches and dents were formed (**Fig. 12(a)**) while impact speed was low. When impact speed increased, cracks started to be formed (**Fig. 12(b)**). The destruction speed decreased as missile mass increased (**Fig. 13**).



(a) scratch, dent | (b) dent, crack

Fig. 10. Destruction modes of Japanese roof tile.

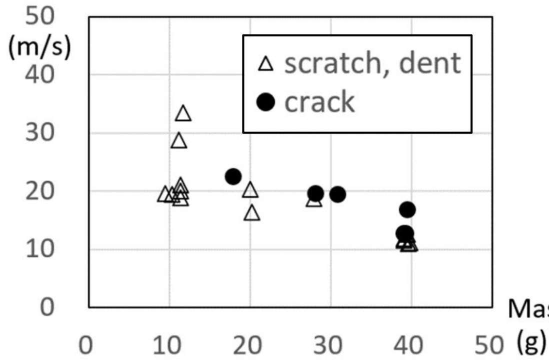
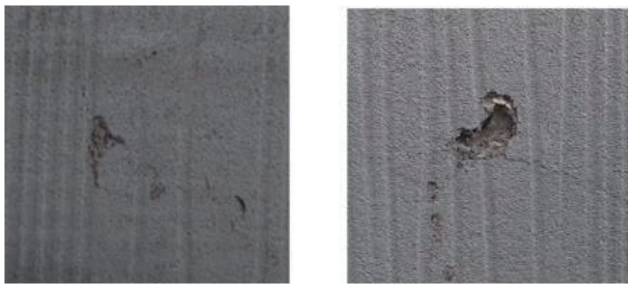


Fig. 11. Effect of missiles' mass and impact speed on destruction modes (Japanese roof tile).



(a) scratch, dent | (b) dent, crack

Fig. 12. Destruction modes of slate tile.

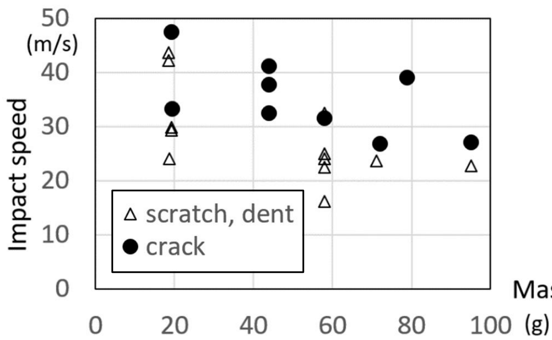


Fig. 13. Effect of missiles' mass and impact speed on destruction modes (slate tile).

(a) scratch, dent (b) dent, crack

Fig. 14. Destruction modes of sheet metal roofing.

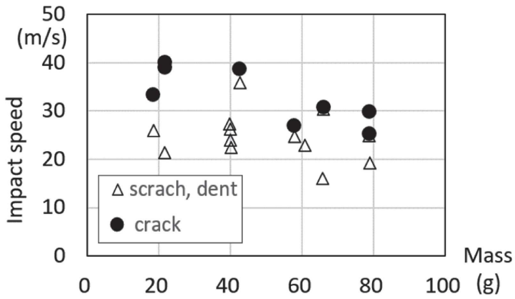


Fig. 15. Effect of missiles' mass and impact speed on destruction modes (light sheet metal roofing).

3.4. Sheet Metal Roofing (Batten Seam Roofing)

In case of light sheet metal (batten seam) roofing, as shown in **Fig. 14(a)**, scratches and dents were formed while impact speed was low. When impact speed gets higher, cracks started to be formed (**Fig. 14(b)**). The destruction speed decreased as missile mass increased (**Fig. 15**).

4. Impact Resistant Performance

When viewing experimental specimens as cladding, the formation of scratches and dents that do not penetrate through to the backside of the specimens does not represent damage to the buildings' interiors. This study thus considered and evaluated the minimum impact speed causing damages that reached the back side of experimental specimens as destruction speed V_C. The relationship between destruction speed V_C [m/s] and the mass of gravel M [g] for each cladding material was found as shown in **Fig. 16**. The V_C–M relationship approximate curves were calculated, and the relationship is represented with the following Eq. (1) and **Table 1**.

$$V_C = CM^{\alpha}. \qquad (1)$$

5. Summary

We carried out impact performance tests to examine the impact resistant performance of cladding against wind- and eruption-borne gravel. Andesite gravel collected from Sakurajima volcano in Japan was injected and collided with float glass, roof models with Japanese roof tiles, slate tiles, and light sheet metal roofing. The impact tests were carried out with various impact speed and mass of the gravel to clarify damage and destruction modes. Assuming future application to risk-evaluation of damages to the building interiors, we evaluated "destruction speed," the minimum impact speed that causes damages greater than cracks reaching the back side of cladding. The relationship between the destruction speed and the mass of gravel for each cladding material was found.

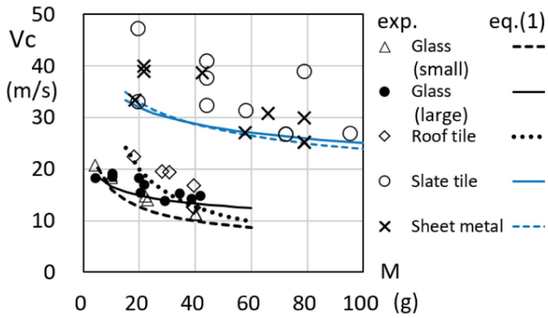


Fig. 16. Relationship between the mass of gravel M [g] and destruction speed V_c [m/s].

Table 1. Coefficients in Eq. (1).

Specimen	C	α
Float glass (small)	35	−0.34
Float glass (large)	24	−0.16
Japanese roof tile	140	−0.65
Slate tile	50	−0.15
Sheet metal	60	−0.20

Acknowledgments

This work was supported by Integrated Program for Next Generation Volcano Research and Human Resource Development 2022 "Development of real-time volcanic ash hazard assessment method," Disaster Prevention Research Institute Kyoto University Collaborative Research: General Collaborative Research-2022G-01 "Development of calculation and prediction method of the characteristics of flying cinder at volcanic eruption," and JSPS KAKENHI Grant Number 22H00248. We express our gratitude for their support.

References:

[1] M. Iguchi and T. Yamada, "Volcanic disaster during the eruptive period since 1955 at Sakurajima volcano," Ann. Disast. Prev. Res. Inst., Kyoto Univ., No.74, pp. 57-72, 2021 (in Japanese with English abstract).

[2] ASCE 7-05, "Minimum Design Loads for Buildings and Other Structures," ASCE (American Society of Civil Engineers) Standard, 2005.

[3] ASTM E1886-04, "Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missiles(s) and Exposed to Cyclic Pressure Differentials," ASTM (American Society for Testing and Materials) Standard, 2004.

[4] ASTM E1996-04, "Standard Specification for Performance of Exte-

rior Windows, Curtain Walls, Doors, and Impact Protective System Impacted by Windborne Debris in Hurricanes," ASTM (American Society for Testing and Materials) Standard, 2004.
[5] ISO 16932, "Glass in Building – Destructive-windstorm-resistant security glazing – Test and classification," ISO (International Organization for Standardization), 2016.
[6] JIS R 3109:2018, "Glass in building-Destructive-windstorm-resistant security glazing-Test method," 2018.
[7] T. Maruyama, H. Kawai, H. Nishimura, and M. Kamo, "An Air-cannon for Impact Resistant Test of Cladding," J. of Wind Engineering, JAWE, Vol.34, No.2, No.119, pp. 31-38, 2009 (in Japanese). https://doi.org/10.5359/jwe.34.31
[8] JIS A 1204:2009, "Test method for particle size distribution of soils," 2009.

Name:
Takashi Maruyama

Affiliation:
Professor, Disaster Prevention Research Institute (DPRI), Kyoto University

Address:
Gokasho, Uji-shi, Kyoto 611-0011, Japan

Brief Career:
1985- Assistant, DPRI, Kyoto University
1998- Assistant Professor, DPRI, Kyoto University
2012- Professor, DPRI, Kyoto University

Selected Publications:
• "Measurement of Aerodynamic Characteristics Using Cinder Models through Free Fall Experiment," Atmosphere, Vol.12, No.5, 608, 2021. https://doi.org/10.3390/atmos12050608
• "Missile Impact Resistant Test of Glasses according to ISO 16932," J. Disaster Res., Vol.8, No.6, pp. 1114-1119, 2013.

Academic Societies & Scientific Organizations:
• The Japan Association for Wind Engineering (JAWE)
• The Architectural Institute of Japan (AIJ)

Name:
Masato Iguchi

ORCID:
0000-0002-4322-5854

Affiliation:
Professor, Disaster Prevention Research Institute (DPRI), Kyoto University

Address:
1722-19 Sakurajima-Yokoyama, Kagoshima-shi, Kagoshima 891-1419, Japan

Brief Career:
1981- Research Associate, DPRI, Kyoto University
1995- Associate Professor, DPRI, Kyoto University
2012- Professor, DPRI, Kyoto University

Selected Publications:
• "Integrated monitoring of volcanic ash and forecasting at Sakurajima volcano, Japan," J. Disaster Res., Vol.14, No.5, pp. 798-809, 2019.
• "Integrated study on forecasting volcanic hazards of Sakurajima volcano, Japan," J. Disaster Res., Vol.15, No.2, pp. 174-186, 2020.
• "Sequence of volcanic activity of Sakurajima volcano, Japan, as revealed by non-eruptive deflation," Front. Earth Sci., 2022.

Academic Societies & Scientific Organizations:
• Volcanological Society of Japan
• International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI)